GEOTECHNICAL INVESTIGATION REPORT

Lake Michigan Bluff Stabilization
Grant Park
Milwaukee County, WI

Prepared for:

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November 2011

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ACRONYMS, ABBREVIATIONS, AND SYMBOLS

AASHTO	American Association of State Highway Transportation Officials
ASTM	American Society of Testing Materials
B-1	Soil boring number
bgs	Below ground surface
bpf	Blows per foot
ft	feet
km	Kilometer
m	Meter
N/B	Northbound
NRCS	Natural Resources Conservation Service
psf	Pounds per square foot
pcf	Pounds per cubic foot
q_{est}	Unconfined compressive strength
S/B	Southbound
SPT	Standard Penetration Test
STA	Station
tsf	Tons per square foot
USH	United States Highway
USCS	Unified Soil Classification System
USDA	United States Department of Agriculture
WDNR	Wisconsin Department of Natural Resources
~	Approximately

1.0 INTRODUCTION

Himalayan Consultants, LLC (Himalayan) has performed this geotechnical investigation in conjunction with the Milwaukee County's proposed plan for stabilizing the Lake Michigan Bluff near Picnic Area #2 in Grant Park, Milwaukee County, Wisconsin (hereafter referred to as the project area) (see Figure 1, Appendix A). The purpose of this investigation was to evaluate the subsurface conditions in the project area, recommend soil parameters for design, and perform global stability analyses of the existing bluff slope.

2.0 HISTORICAL BACKGROUND

Bluffs (ranging in height from approximately 6 m (~20 feet) to 37 m (~121feet) located on the western shore of Lake Michigan have historically been unstable or marginally unstable due to a combination of factors including problematic slope geometry, freeze/thaw action, wind erosion, lake wave-induced erosion at the toe of the bluffs, and erosion caused by groundwater seepage from glacial outwash deposits within the bluff profile [Ref. 1, 2]. It appears that the seepage-induced erosion in combination with the build-up of hydrostatic pressures in the soil profile due to insufficient drainage has continued to contribute to the instability of the bluff slopes [Ref. 2].

3.0 GEOLOGICAL SETTING

A review of the USDA Natural Resources Conservation Service (NRCS) Soil Survey of Milwaukee County, Wisconsin indicates that the soils at the site consist mainly of rough broken land (Ry) and Morley silt loam (MzdB) [Ref. 3]. The rough broken land (Ry) soils are formed in clayey till and/or colluvium. The Morley silt loam (MzdB) is formed in loess over calcareous clayey till and is considered well drained. A typical profile of these soils is described below:

- Rough broken land (Ry) consists of:
  - 0-10 inches: silty clay. and
  - 10-60 inches: silty clay loam.

- Morley silt loam (MzdB) consists of:
  - 0-8 inches: silt loam
  - 8-12 inches: silty clay loam
  - 12-28 inches: silty clay, and
  - 28-60 inches: silty clay loam.

Depth to the seasonal high water table in these soils is estimated to be more than 80 inches [Ref. 3].

A study of morphologic features completed in 1980 along an approximately 62-mile (100 km) section of Wisconsin's Lake Michigan shoreline revealed six major kinds of bluff types (Ref. 1). Based on this study, the bluff slopes in the project area are generally steep with bluff angles of 30 to 40 degrees or more. The geology of three of the six types, which includes the bluff type present in the project area, are described as having top and bottom glacial till (materials deposited by melting glaciers in irregular sheets and ranging in material sizes from clay to cobbles and boulders) or glaciolacustrine deposits (materials deposited in lakes by meltwater from glaciers and ranging in material sizes from silt to clays) with a sand layer, or lens, in the middle.

According to Edil and Mickelson (1995), the till is fractured to depths of approximately 33 feet (~10 m) or more providing rapid groundwater recharge to the intermediate sand layers in the profile [Ref. 2].

4.0 SUBSURFACE INVESTIGATION

4.1 Field Investigation

On October 10, 2011, Professional Service Industries, Inc. (PSI), under a contract with Himalayan, advanced one test boring (B-1) in the project area. Boring was located at the crest of the bluff area, approximately 24 feet west-southwest from the gully's headwall (see Figure 2, Appendix A). Boring was advanced to a depth of approximately 94 feet below the existing ground surface (bgs) (approximate Mean Sea Elevation = 651 feet), until split spoon refusal was observed.

The boring location was determined and marked in the field by Collins Engineers, Inc. (CEI) with minor field adjustments conducted by Himalayan.. Ground surface elevation of the boring location was also provided by CEI.

Borings were advanced with a rotary drilling rig in accordance with the specifications for the Standard Penetration Test (SPT) ASTM D-1586 (AASHTO T206) [Ref. 4]. Soil sampling was performed at every 2.5-foot interval for the first 10 feet and at every 5-foot interval thereafter using a 2-inch outside diameter by 1.375-inch inside diameter split-spoon sampler. The split-spoon sampler was driven 18 inches using a 140-pound hammer, and the blow counts were recorded for every six-inch penetration. The SPT (Standard Penetration Resistance) N-value, which is the total number of blows required to penetrate the last 12 inches, was recorded for each sample interval throughout the borings.

During field activities, Himalayan and PSI visually classified the soils and prepared a field log of the boring. Upon completion of the drilling operations, the soil samples were taken to Himalayan's office for further examination and determination of natural water content. Each sample was examined and classified by Himalayan in accordance with the Unified Soil Classification System (USCS).

Upon completion of sampling, the borehole was properly abandoned/backfilled as per the requirements of Wisconsin Administrative Code NR 141.

4.2 Field and Laboratory Testing

Estimates of unconfined compressive strengths (q_{est}) were conducted on cohesive samples in the field using a pocket penetrometer. The q_{est} values for the subsurface soils ranged from 0.50 to over 4.50 tons/square foot (tsf). The standard penetration resistance (N value) for the soils recorded during drilling ranged from 6 to over 77 blows per foot (bpf). The natural water content determinations were performed on majority of the samples obtained in accordance with applicable ASTM/AASHTO specifications. The natural water content for the soils ranged from 9 to 31 percent. Refer to the Soil Boring Logs in Appendix B for q_{est} values, N values, and Water Content Determination test results.

Additionally, three samples of silty and sandy soils retrieved from 13.5 to15 feet bgs, 28.5 to 30 feet bgs, and 38.5 to 40 feet bgs were submitted to PSI for particle size analysis (ASTM D-421) (see laboratory report in Appendix C).

5.0 SITE CONDITIONS

5.1 Surface Conditions

Based on field observations, a gully consisting of almost vertical walled channel has formed in the project area accompanied by rotational slumps of the soils along the side walls. It appears that intermittent surface and subsurface water flows through the gully continue to cause erosion of the subsoil leading sections of the gully head (head wall) to collapse and transport the debris derived from the headwall and gully sides (sidewalls) down toward the Lake Michigan beach area.

Dense vegetation was observed on either side of the failed bluff slope, a portion of which appears to be relatively steep (1.3H:1V) with poor access to the Lake Michigan beach area.

See Photographs #1 and #2 in Appendix E for the upper and lower sections of the existing unstable (failed) slope.

5.2 Subsurface Conditions

Based on the subsurface soils encountered in the boring, fine silty sands were present below topsoil to a depth of about 2.5 feet bgs, followed by sandy clays from approximately 2.5 to 10 feet bgs. Well graded sands were encountered below sandy clays between 10 to 18.5 feet bgs. Sandy/clayey silts were encountered below the well graded sands from 18.5 to 33.5 feet bgs. Gray silty clays were encountered between 33.5 to 38.5 feet bgs, followed by: silty sands to sandy silts from 38.5 to 48.5 feet bgs and silty clays from 48.5 to 88.5 feet bgs. Gray hard sandy silt (hard pan) was observed below silty clays from approximately 88.5 to 93.5 feet bgs.

Obstruction (weathered bedrock) was encountered at 93.5 feet bgs. Note that the depth to bedrock in the project area ranges from 50 to 100 feet bgs [Ref. 5].

In general, the above soil profile correlates well with the geology of the bluff in the project area from previous investigation [Ref. 1], described as having top and bottom till or glaciolacustrine soils with a sand layer, or lens, in the middle.

5.3 Groundwater Conditions

Based on the change of color (from brown to gray) and saturated conditions observed in the retrieved soil samples, it appears that groundwater occurs in the project area at approximately 28 feet (approximate Elevation: 623 feet MSL) bgs. It should be noted that groundwater depths can vary throughout the year, depending on several factors that include seasonal variations in precipitation, infiltration, and surface water runoff.

Because of the drilling method utilized (mud drilling using bentonite slurry), no groundwater observation was made after completion of boring.

6.0 SOIL PARAMETERS

Soil parameters have been developed based on the field and laboratory testing performed as part of this investigation, and also on historical tests performed on soil of similar properties. Table 1 provides tabulation of the following soil parameters:

- Unconfined compressive strength of cohesive soils, q_u
- Cohesion, c
- Angle of internal friction, φ
- Moist unit weight, γ
- Hydraulic conductivity, k

Note that the cohesion values presented in the tables for silty/sandy clays and silts represent the undrained shear strength values of these soils (φ =0 condition).

TABLE 1. Recommended Soil Parameters Grant Park Bluff Stabilization Milwaukee County, WI						
Depth (ft)	**Soil Stratum**	**q_u (psf)**	**c (psf)**	**φ deg**	**Moist Unit Weight (pcf)**	**k (Range)* (cm/s)**
0-2.5	Silty Sand/Clayey silt	N/A	N/A	27	95	10^{-5} to 10^{-3}
2.5-10	Sandy Clay	2,600	1,300	N/A	120	10^{-6} to 10^{-4}
10-18.5	Sand	N/A		34	120	10^{-3} to 10^{-1} (6.25×10^{-2})**
18.5-33.5	Sandy/Clayey Silt	2500	1,250	N/A	125	10^{-6} to 10^{-4}
33.5-38.5	Silty Clay	5000	2,500	N/A	130	10^{-9} to 10^{-6}
38.5-48.5	Silty Sand	N/A	N/A	32	125	10^{-5} to 10^{-3}
48.5-88.5	Silty Clay	5,500	2,750	N/A	128	10^{-9} to 10^{-6}
88.5-93.5	Clayey Silt	9,000	4,500	N/A	132	10^{-9} to 10^{-6}
> 93.5	Weathered Bedrock	0	0	35	140	N/A

Notes:
* Source: Applied Hydrogeology [Ref. 6]
**Based on Hazen Method ($k = cD^2_{10}$), where C = 1 to 1.5, and
D_{10} = Effective size in millimeters (obtained from Particle Size Analysis on the on-site soil sample-see report in Appendix C) [Ref. 7].
Deg = degrees; ft = feet; psf = pounds per square foot; pcf = pounds per cubic foot; cm/s = centimeters per second ; N/A = Not Applicable

7.0 SLOPE STABILITY ANALYSIS

Global stability analyses of the existing bluff slopes were performed using GEO5, a computer software, which uses the Bishop's method (circular slip surface) and Sarma's Method (polygonal slip surface) to determine the global stability. Analyses were carried out for the existing failed slope and unfailed slope immediately adjacent to the south. The slope geometries used in the analysis were based on the information provided by CEI.

Based on the soil information obtained from the test boring and slope geometry, the factors of safety for the global stability were found to be as follows:

TABLE 2. Global Stability Analyses Results Grant Park Bluff Stabilization Milwaukee County, WI		
Existing Bluff Slope	**Factor of Safety**	
	Bishop (Circular Slip Surface)	Sarma (Polygonal Slip Surface)
Failed	2.12	1.09
Adjacent Unfailed	1.15	1.29

Refer to Appendix D for the global stability analyes reports.

8.0 RECOMMENDATIONS

It is Himalayan's understanding that Collins is developing a design plan for stabilization of the bluff slopes. The current bluff slopes are relatively steep, even with the failed condition to maintain a factor of safety of 1.5 to 2.0 for global stability. Since this is a park area, the ideal slope stabilization method is anticipated to incorporate structural elements that blend with the surrounding environment.

According to CEI, preliminary analysis indicates that a combination of gabion structure wall and rip-rap shore erosion at the toe of the slope may be the solution for this project. This will require earthwork to create stable benches upon which to construct the gabions. The rip rap may be placed from lake side (utilizing barge) or from the top of the slope. Feasibility of these alternates is being reviewed by CEI as a part of this project's scope of work. It is recommended that the slope stabilization design plan incorporate the anticipated additional loading from the heavy construction equipment as part of the stability considerations of the existing failed and adjacent unfailed bluff slopes.

9.0 LIMITATIONS

Himalayan prepared this report for CEI and Milwaukee County to use as part of the evaluation of subsurface conditions in the project area. This report was prepared in accordance with the currently accepted geotechnical engineering practices as conducted within the site region by similar qualified consultants. Because the evaluation is based upon subsurface physical data obtained from soil boring only at specific location and time and only to the depths sampled, the report does not reflect potential variations in the subsurface conditions that could occur between or beyond the limits of the test boring that was used for analysis. The conclusions or recommendations contained represent our professional opinions. No warranty or guarantee is expressed or implied. If variations are encountered and/or the project scope is altered, further evaluation and testing should be performed by a geotechnical engineer.

10.0 REFERENCES

1. Christopher S. Peters (July 1983). The effect of Lake-Level Fluctuations on the Geomorphioc Evolution of The Lake Michigan Bluffs in Wisconsin, Geoscience, Wisconsin.

2. Eric W. Bahner, P.E., M. ASCE and Gary Jackson/ Edward E. Gillen Company (2007). Slope Drainage Improvement Using Wick Drains Installed by HDD Methods, Proceedings for the First North American Landslide Conference, Vail Colorado; AEG Special Publication No. 23.

3. United States Department of Agriculture Natural Resources Conservation Service (2007). URL: http://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx

4. American Society for Testing and Materials (1992). Method for Penetration Test and Split Barrel Sampling of Soils.

5. L.C. Trotta and R.D. Cotter (1973): Depth to Bedrock in Wisconsin, Geological and Natural History Survey, University of Wisconsin.

6. C. W. Fetter (1988). Applied Hydrogeology, Third Edition

7. Braja M. Das (2006). Principles of Geotechnical Engineering, Sixth Edition.

APPENDICES

Appendix A. Figures
Figure 1: Project Area Location Map
Figure 2: Boring Location Map

Appendix B. Soil Boring Logs and Unified Soil Classification System

Appendix C. Particle Size Analyses Report

Appendix D. Global Stability Analyses Report

Appendix E. Site Photographs

APPENDIX A

FIGURES

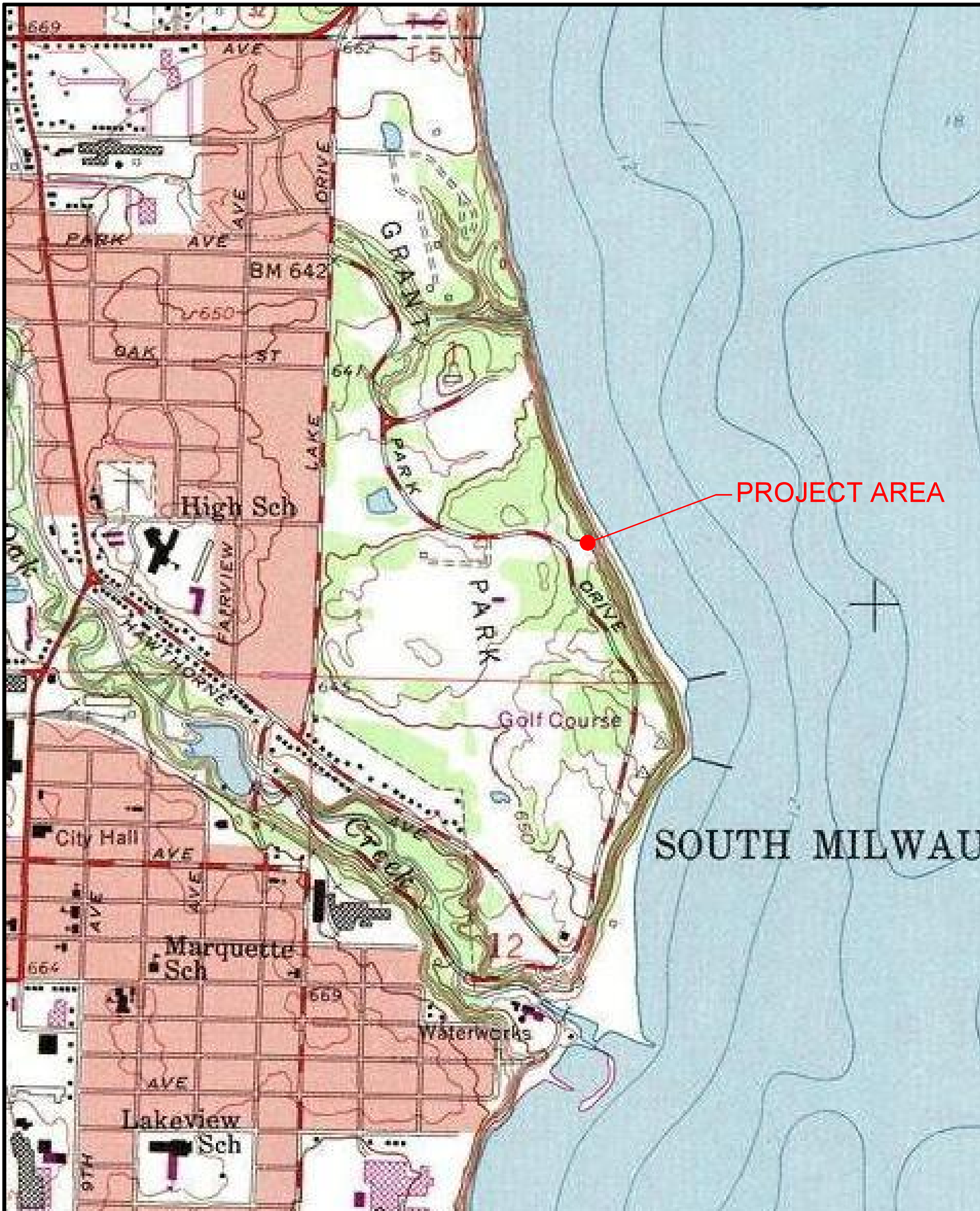

Figure 1

Project Area Location Map

Project ID: WP192071
Grant Park FEMA Restoration

Source:
National Geographic
USGS 7.5' Topographic Map - South Milwaukee, WI (1992)

Scale: 1 inch = ~1,200 feet

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Figure

2

Boring Location Map

Project ID No: WP192071

Grant Park FEMA Restoration

Base Map Provided By Collins Engineering

Graphic Scale

1 inch = ~60 feet

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APPENDIX B

SOIL BORING LOGS

AND

UNIFIED SOIL CLASSIFICATION SYSTEM

Himalayan Consultants, LLC

W156 N11357 Pilgrim Rd, Germantown, WI 53022 Tel: (262) 502-0066 Fax: (262) 502-0077

LOG OF TEST BORING

Project: Grant Park - Bluff Restoration
South Milwaukee, WI

Location: Grant Park

Boring No. B-1
Surface Elevation 651
Job No. 11021.046
Sheet 1 of 6

SAMPLE No.	Type	Recov.	Moist.	N-Value	Depth (ft.)	VISUAL CLASSIFICATION and Remarks	qest (qu) tsf	W %	LL	PL	DD pcf	PID ppm
					0	TOPSOIL/CLAYEY SILT (POSSIBLE FILL/ML): Soft, dark brown, moist						
1	SS	8"	D	9		SILTY SAND (SM): Loose, brown, moist, fine grained		16				
					2.5	SANDY CLAY (CL): Stiff, gray, moist						
2	SS	14"	M	9			1.0	22				
					5							
3	SS	18"	M	7			1.5	26				
					7.5							
4	SS	18"	M	6			1.5	24				
					10	SAND (SW): Dense, gray, moist, some fine gravel and trace silt, well graded						
					12.5							
							-					

WATER LEVEL OBSERVATIONS

While Drilling 28 feet
Upon Completion of Drilling N/A
Time After Drilling N/A
Depth to Water N/A
Depth to Cave-in 20 feet

GENERAL NOTES

Start 10/10/11 Complete 10/10/11
Crew Chief DZ Rig PSI
Drilling Method: 30 ft of HSA casing
Bentonite Mud Rotary
Split Spoons

NOTE: Soil stratification lines represent approximate boundaries between soil types and transitions may be gradual.

LOG OF TEST BORING

Himalayan Consultants, LLC

Project: Grant Park - Bluff Restoration
South Milwaukee, WI
Location: Grant Park

Boring No. B-1
Surface Elevation 651
Job No. 11021.046
Sheet 2 of 6

W156 N11357 Pilgrim Rd, Germantown, WI 53022 Tel: (262) 502-0066 Fax: (262) 502-0077

SAMPLE						VISUAL CLASSIFICATION and Remarks	SOIL PROPERTIES					PID ppm
No.	Type	Recov.	Moist.	N-Value	Depth (ft.)		q_{est} (q_u) tsf	W %	LL	PL	DD pcf	
5	SS	14"	M	31	15							
					17.5	Driller's notes: Hard drilling possible cobbles						
						SANDY/CLAYEY SILT (ML): Stiff, gray, moist to wet	-	31				
6	SS	12"	W	19	20							
					22.5							
7	SS	18"	M	14	25		1.5	18				
					27.5							
8	SS	18"	M	11	30		1.0					

NOTE: Soil stratification lines represent approximate boundaries between soil types and transitions may be gradual.

LOG OF TEST BORING

Himalayan Consultants, LLC

Project	Grant Park - Bluff Restoration
	South Milwaukee, WI
Location	Grant Park

Boring No.	B-1
Surface Elevation	651
Job No.	11021.046
Sheet	3 of 6

W156 N11357 Pilgrim Rd, Germantown, WI 53022 Tel: (262) 502-0066 Fax: (262) 502-0077

SAMPLE						VISUAL CLASSIFICATION and Remarks	SOIL PROPERTIES					PID ppm
No.	Type	Recov.	Moist.	N-Value	Depth (ft.)		q_{est} (q_u) tsf	W %	LL	PL	DD pcf	
					32.5							
9	SS	18"	M	16	35	SILTY CLAY (CL): Very stiff, gray, moist, trace coarse sand	2.5	24				
					37.5							
10	SS	18"	M	31	40	SILTY SAND to SANDY SILT (SP-SM): Medium dense, gray, wet, poorly graded, fine grained	-					
					42.5							
11	SS	18"	M	14	45		-	22				
					47.5	SILTY CLAY (CL): Medium stiff to very						

NOTE: Soil stratification lines represent approximate boundaries between soil types and transitions may be gradual.

LOG OF TEST BORING

Himalayan Consultants, LLC

Project	Grant Park - Bluff Restoration	Boring No.	B-1
	South Milwaukee, WI	Surface Elevation	651
		Job No.	11021.046
Location	Grant Park	Sheet	4 of 6

W156 N11357 Pilgrim Rd, Germantown, WI 53022 Tel: (262) 502-0066 Fax: (262) 502-0077

SAMPLE						VISUAL CLASSIFICATION and Remarks	SOIL PROPERTIES					PID ppm
No.	Type	Recov.	Moist.	N-Value	Depth (ft.)		q_{est} (q_u) tsf	W %	LL	PL	DD pcf	
						stiff, gray, moist to wet, trace coarse sand	2.5	22				
12	SS	18"	M	18	50							
					52.5							
						Disturbed soil sample						
13	SS	6"	W	24	55							
					57.5							
							2.5	21				
14	SS	18"	M	19	60							
					62.5							
							3.0	16				
15	SS	18"	M	23	65							

NOTE: Soil stratification lines represent approximate boundaries between soil types and transitions may be gradual.

LOG OF TEST BORING

Himalayan Consultants, LLC

W156 N11357 Pilgrim Rd, Germantown, WI 53022 Tel: (262) 502-0066 Fax: (262) 502-0077

Project: Grant Park - Bluff Restoration
South Milwaukee, WI

Location: Grant Park

Boring No. B-1

Surface Elevation 651

Job No. 11021.046

SAMPLE No.	Type	Recov.	Moist.	N-Value	Depth (ft.)	VISUAL CLASSIFICATION and Remarks	q_{est} (q_u) tsf	W %	LL	PL	DD pcf	PID ppm
					67.5							
16	SS	18"	M	26	70		3.0	17				
					72.5							
17	SS	18"	M	28	75		3.0	21				
					77.5							
18	SS	18"	M	38	80		4.0	15				
					82.5							

NOTE: Soil stratification lines represent approximate boundaries between soil types and transitions may be gradual.

LOG OF TEST BORING

Himalayan Consultants, LLC

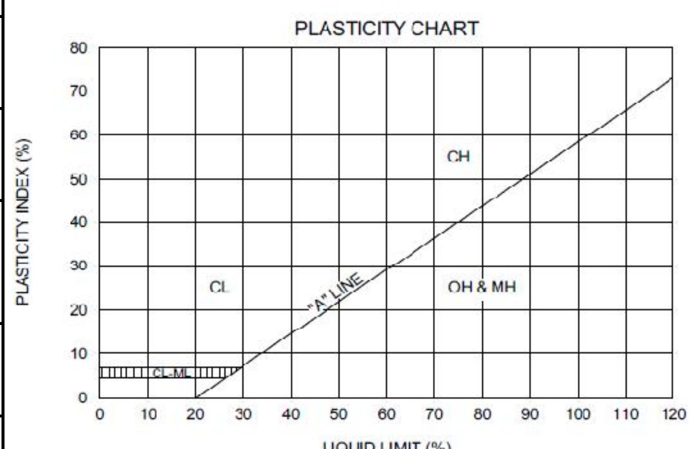
Project	Grant Park - Bluff Restoration
	South Milwaukee, WI
Location	Grant Park
Boring No.	B-1
Surface Elevation	651
Job No.	11021.046
Sheet	6 of 6

W156 N11357 Pilgrim Rd, Germantown, WI 53022 Tel: (262) 502-0066 Fax: (262) 502-0077

SAMPLE No.	Type	Recov.	Moist.	N-Value	Depth (ft.)	VISUAL CLASSIFICATION and Remarks	q_{est} (q_u) tsf	W %	LL	PL	DD pcf	PID ppm
19	SS	16"	M	77	85		4.0	17				
					87.5	CLAYEY SILT (ML): Hard, gray, moist, little coarse sand to fine gravel						
20	SS	18"	M	68	90		4.5+	9				
					92.5							
21	SS	0"		50		Drill bit and split spoon refusal. Possible bedrock. Dolomite chips were noted in the cuttings and in the split spoon.						
					95	End of Boring = 93.5 Feet Borehole backfilled with bentonite chips						
					97.5							
					100							

NOTE: Soil stratification lines represent approximate boundaries between soil types and transitions may be gradual.

UNIFIED SOIL CLASSIFICATION SYSTEM (ASTM D-2487)

Major Divisions			Group Symbols		Typical Names	Laboratory Classification Criteria		
Course grained soils (More than half of material is larger than No. 200 sieve size)	Gravels (More than half of course fraction is larger than No. 4 sieve size)	Clean gravels (Little or no fines)	GW		Well-graded gravels, gravel-sand mix-tures, little or no fines	Determine percentages of sand and gravel from grain size curve Depending on percentage of fines (fraction smaller than No. 200 sieve size), course soils are classified as follows: Less than 5 percent GW, GP, SW, SP More than 12 perce GM, GC, SM, SC 5 to 12 percent Borderline cases requiring dual symbols	$C_u = \frac{D_{60}}{D_{10}}$ reater than 4; $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ between 1 and 3	
			GP		Poorly graded gravels, gravel-sand mix-tures, little or no fines		Not meeting all gradation requirements for GW	
		Gravels with fines (Appreciable amount of fines)	GM[a]	d	Silty gravels, gravel-sand-silt mixtures		Atterberg limits below "A" line or P.I. less than 4	Above "A" line with P.I> between 4 and 7 are borderline cases requiring use of dual symbols
				u				
			GC		Clayey gravels, gravel-sand-clay mix-tures		Atterberg limits below "A" line with P.I. greater than 7	
	Sands (More than half of course fraction is smaller than No. 4 sieve size)	Clean sands (Little or no fines)	SW		Well-graded sands, gravelly sands, little or no fines		$C_u = \frac{D_{60}}{D_{10}}$ reater than 6; $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ between 1 and 3	
			SP		Poorly graded sands, gravelly sands, little or no fines		Not meeting all gradation requirements for SW	
		Sands with fines (Appreciable amount of fines)	SM[a]	d	Silty sands, sand-silt mixtures		Atterberg limits above "A" line or P.I. less than 4	Limits plotting in hatched zone with P.I. between 4 and 7 are borderline cases requiring use of dual symbols
				u				
			SC		Clayey sands, sand-clay mixtures		Atterberg limits above "A" line with P.I. greater than 7	
Fine grained soils (More than half material is smaller than No. 200 sieve)	Silts and clays (Liquid limit less than 50)		ML		Inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts with slight plasticity			
			CL		Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays			
			OL		Organic silts and organic silty clays of low plasticity			
	Silts and clays (Liquid limit greater than 50)		MH		Inorganic silts, micaceous or diatoma-ceous fine sandy or silty soils, elastic silts			
			CH		Inorganic clays of high plasticity, fat clays			
			OH		Organic clays of medium to high plasticity, organic silts			
	Highly organic soils		Pt		Peat and other highly organic soils			

a Division of GM and SM groups into subdivisions of d and u are for roads and airfields only. Subdivision is based on Atterberg limits; suffix d used when L.L. is 28 or less and the P.I. is 6 or less; the suffix u used when L.L. is greater than 28

b Borderline classifications: used for soils possessing characteristics of two groups; are designated by combinations of group symbols. For example: GW-GC, well-graded gravel-sand mixture with clay binder

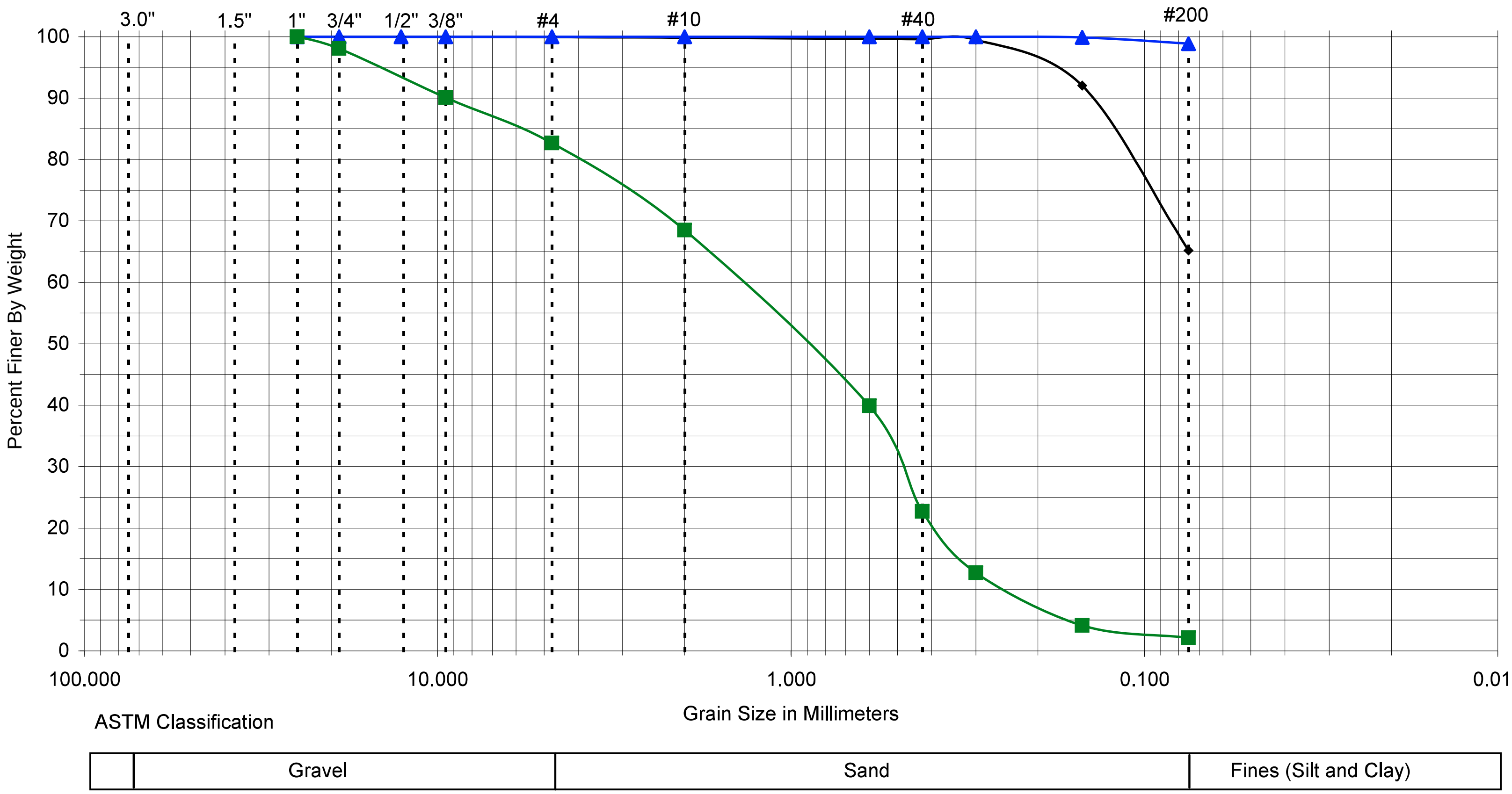
APPENDIX C

PARTICLE SIZE ANALYSES

REPORT

Information To Build On
Engineering • Consulting • Testing

REPORT OF PARTICLE-SIZE ANALYSIS OF SOIL



Key	Boring Number	Depth	%Gravel	%Sand	%Fines
■	B-1	13.5'-15'	17.3	80.5	2.1
▲	B-1	28.5'-30'	0.0	1.1	98.9
◆	B-1	38.5'-40'	0.1	34.7	65.2

Grant Park Restoration, South Milwaukee, WI	File No.	**11021.046**

Professional Service Industries • W237 N2878 Woodgate Road • Pewaukee, WI 53072 • 262-347-0898 • 262-347-2256 (Fax)

APPENDIX D

GLOBAL STABILITY ANALYSES

REPORT

Figure **D-1**	**Global Stability Analysis** Grant Park FEMA Restoration *Base Map Provided By Collins Engineering*	Graphic Scale 1 inch = ~60 feet	**Himalayan Consultants, LLC** Engineers and Hydrogeologists W156 N11357 Pilgrim Road Germantown, Wisconsin 53022 Phone: (262) 502-0066 Fax: (262) 502-0066

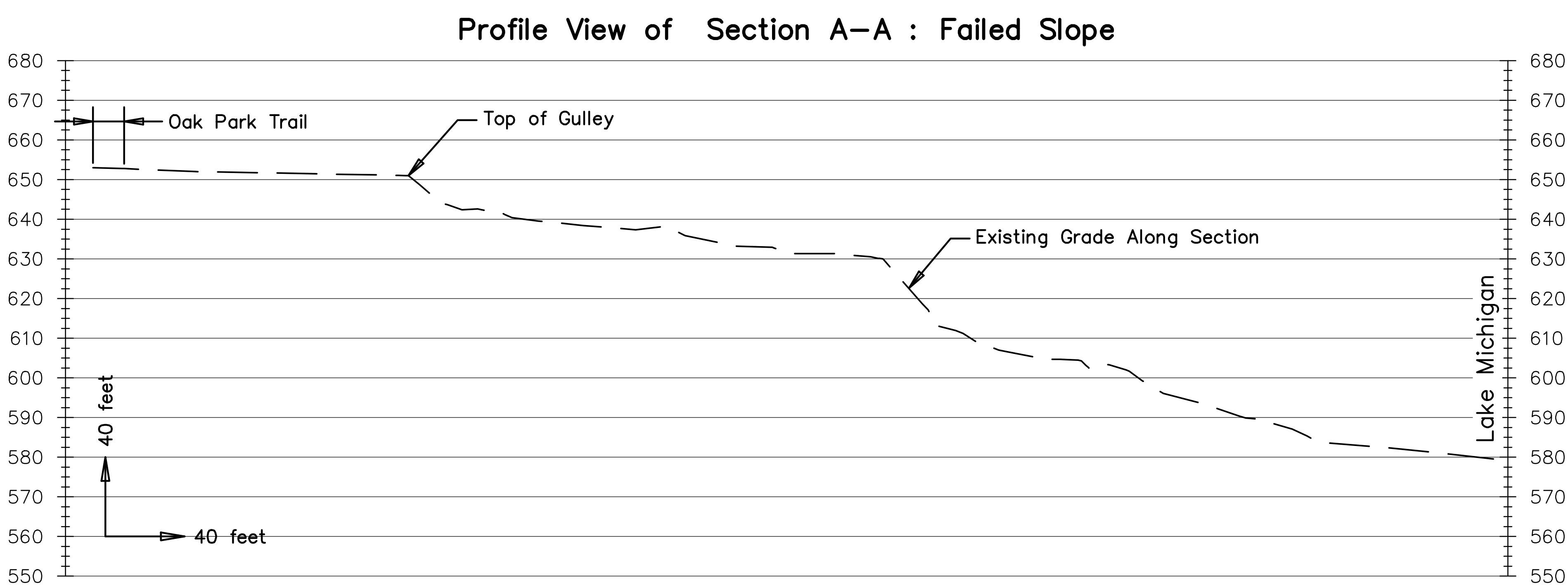


Figure
D-2

Global Stability Analysis
Grant Park FEMA Restoration
Base Map Provided By Collins Engineering

Himalayan Consultants, LLC
Engineers and Hydrogeologists
W156 N11357 Pilgrim Road
Germantown, Wisconsin 53022
Phone: (262) 502-0066
Fax: (262) 502-0066

Profile View of Section B–B : Adjacent Unfailed Slope

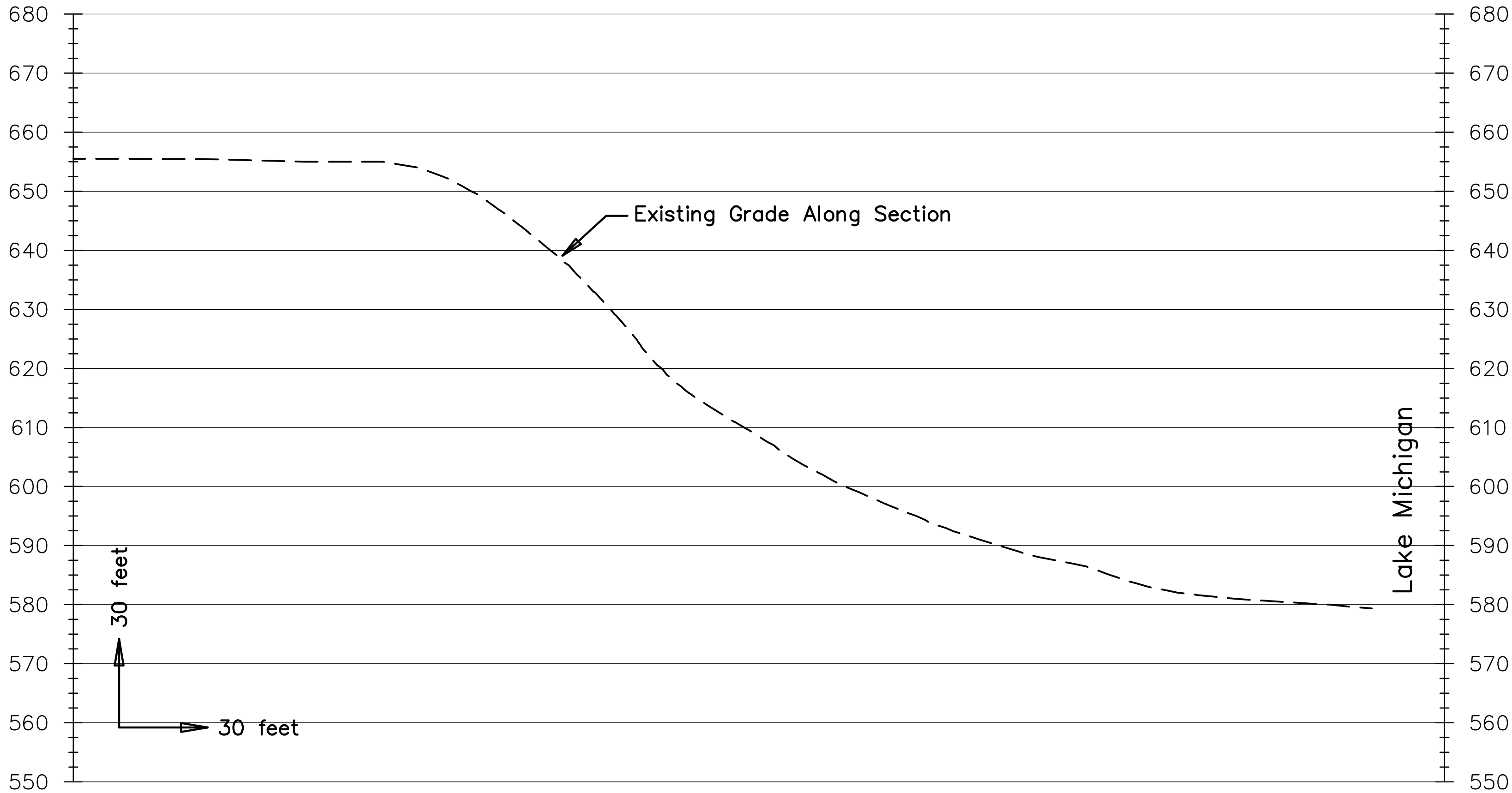


Figure
D-3

Global Stability Analysis
Grant Park FEMA Restoration
Base Map Provided By Collins Engineering

Himalayan Consultants, LLC
Engineers and Hydrogeologists
W156 N11357 Pilgrim Road
Germantown, Wisconsin 53022
Phone: (262) 502-0066
Fax: (262) 502-0066

EXISTING FAILED SLOPE

(Section A–A)

Profile View of Section A–A : Failed Slope

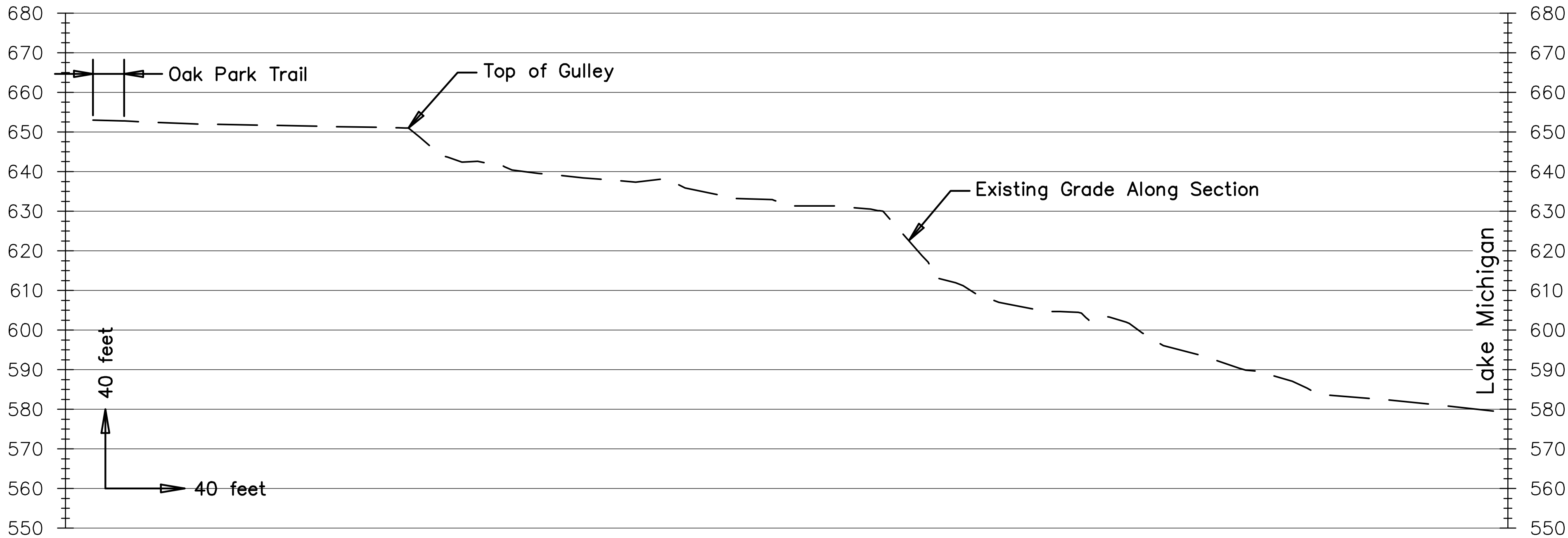


Figure
D-2

Global Stability Analysis
Grant Park FEMA Restoration
Base Map Provided By Collins Engineering

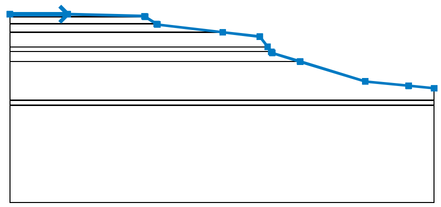
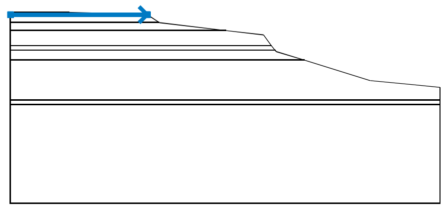
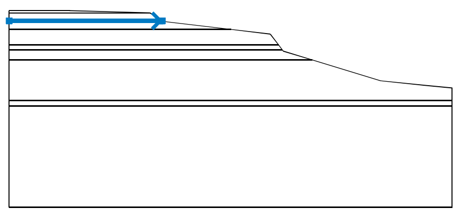
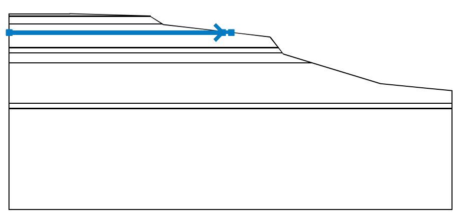
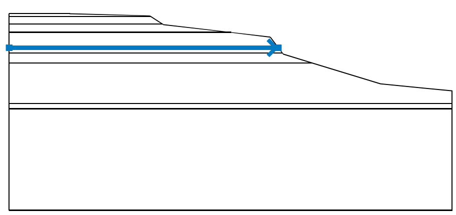
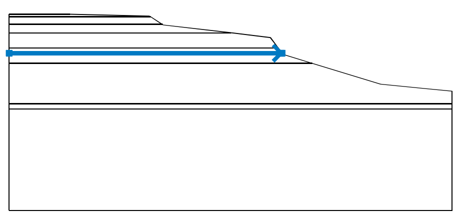
Himalayan Consultants, LLC
Engineers and Hydrogeologists
W156 N11357 Pilgrim Road
Germantown, Wisconsin 53022
Phone: (262) 502-0066
Fax: (262) 502-0066

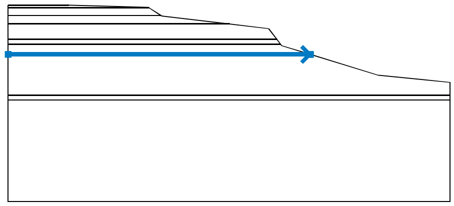
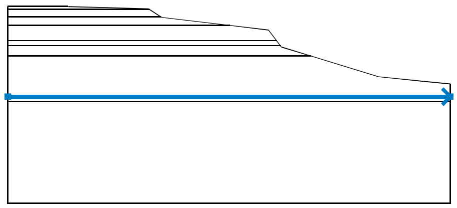
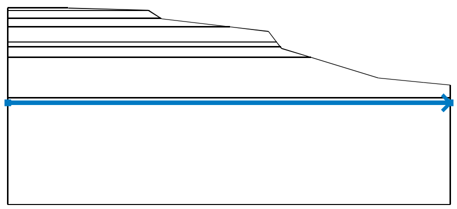
Slope Stability Analysis

Project: Grant Park

Task : Check for Global Stability – Existing Failed Slope
Circular Slip Surface
Description : Grant Park Bluff Stabilization, Milwaukee County
Author : GKA
Date : 11/2/2011
Analysis type : in effective parameters

Interface

Number	Interface location	Coordinates of interface points [ft]					
		x	z	x	z	x	z
1		-60.00	73.43	0.00	73.43	79.49	71.41
		80.24	70.93	91.97	63.43	92.92	62.82
		160.65	54.93	199.19	50.44	207.29	39.93
		211.14	34.93	212.08	33.71	240.95	24.93
		308.59	4.36	353.35	0.00	380.00	-2.60
2		-60.00	70.93	80.00	70.93	80.24	70.93
3		-60.00	63.43	90.00	63.43	91.97	63.43
4		-60.00	54.93	152.00	54.93	160.65	54.93
5		-60.00	39.93	205.00	39.93	207.29	39.93
6		-60.00	34.93	210.00	34.93	211.14	34.93

Number	Interface location	Coordinates of interface points [ft]					
		x	z	x	z	x	z
7		-60.00	24.93	240.00	24.93	240.95	24.93
8		-60.00	-15.07	380.00	-15.07		
9		-60.00	-20.07	380.00	-20.07		

Soil parameters - effective stress state

Number	Name	Pattern	φ_{ef} [°]	c_{ef} [psf]	γ [pcf]
1	Silty Sand/Clayey Silt		27.00	0.0	95.0
2	Sandy Clay		0.00	1300.0	120.0
3	Sand		34.00	0.0	120.0
4	Sandy/Clayey Silt		0.00	1250.0	125.0
5	Silty Clay-1		0.00	2500.0	130.0
6	Silty Sand to Clayey Silt		32.00	0.0	125.0
7	Silty Clay-2		0.00	2750.0	128.0
8	Clayey Silt		0.00	4500.0	132.0

Number	Name	Pattern	φ_{ef} [°]	c_{ef} [psf]	γ [pcf]
9	Weathered Bedrock		30.00	0.0	140.0

Soil parameters - uplift

Number	Name	Pattern	γ_{sat} [pcf]	γ_s [pcf]	n [–]
1	Silty Sand/Clayey Silt		95.0		
2	Sandy Clay		120.0		
3	Sand		120.0		
4	Sandy/Clayey Silt		125.0		
5	Silty Clay-1		130.0		
6	Silty Sand		125.0		
7	Silty Clay-2		128.0		
8	Clayey Silt		132.0		
9	Weathered Bedrock		140.0		

Soil parameters

Silty Sand/Clayey Silt

Unit weight :	γ	=	95.0 pcf
Angle of internal friction :	φ_{ef}	=	27.00 °
Cohesion of soil :	c_{ef}	=	0.0 psf
Saturated unit weight :	γ_{sat}	=	95.0 pcf

Sandy Clay

Unit weight :	γ	=	120.0 pcf
Angle of internal friction :	φ_{ef}	=	0.00 °
Cohesion of soil :	c_{ef}	=	1300.0 psf
Saturated unit weight :	γ_{sat}	=	120.0 pcf

Sand

Unit weight : γ = 120.0 pcf
Angle of internal friction : φ_{ef} = 34.00 °
Cohesion of soil : c_{ef} = 0.0 psf
Saturated unit weight : γ_{sat} = 120.0 pcf

Sandy/Clayey Silt
Unit weight : γ = 125.0 pcf
Angle of internal friction : φ_{ef} = 0.00 °
Cohesion of soil : c_{ef} = 1250.0 psf
Saturated unit weight : γ_{sat} = 125.0 pcf

Silty Clay-1
Unit weight : γ = 130.0 pcf
Angle of internal friction : φ_{ef} = 0.00 °
Cohesion of soil : c_{ef} = 2500.0 psf
Saturated unit weight : γ_{sat} = 130.0 pcf

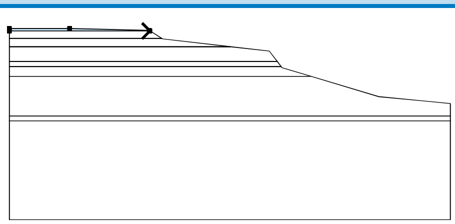
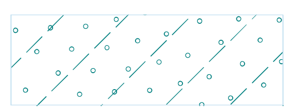
Silty Sand to Clayey Silt
Unit weight : γ = 125.0 pcf
Angle of internal friction : φ_{ef} = 32.00 °
Cohesion of soil : c_{ef} = 0.0 psf
Saturated unit weight : γ_{sat} = 125.0 pcf

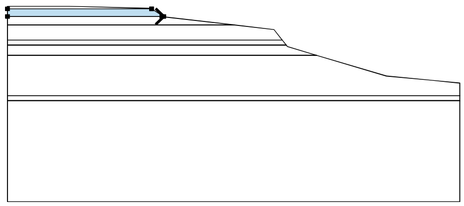
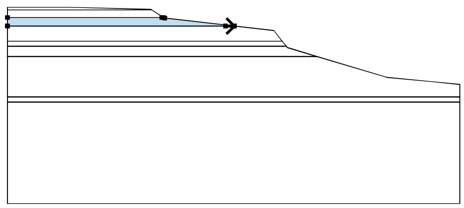
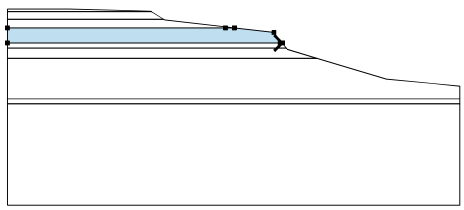
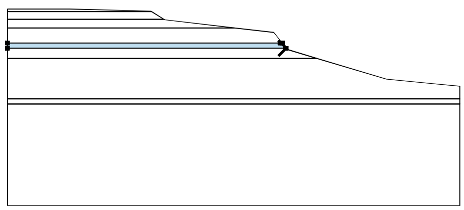
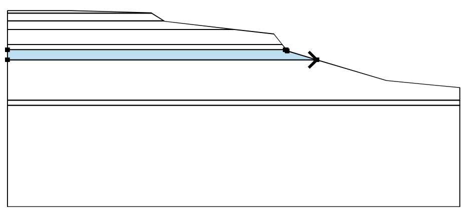
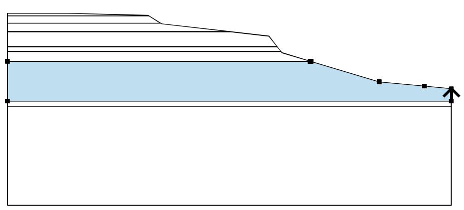
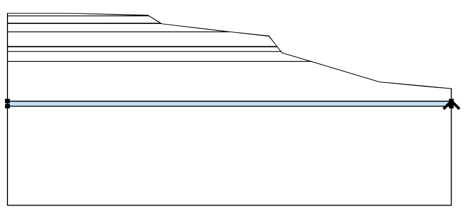
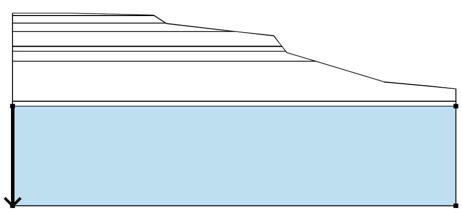
Silty Clay-2
Unit weight : γ = 128.0 pcf
Angle of internal friction : φ_{ef} = 0.00 °
Cohesion of soil : c_{ef} = 2750.0 psf
Saturated unit weight : γ_{sat} = 128.0 pcf

Clayey Silt
Unit weight : γ = 132.0 pcf
Angle of internal friction : φ_{ef} = 0.00 °
Cohesion of soil : c_{ef} = 4500.0 psf
Saturated unit weight : γ_{sat} = 132.0 pcf

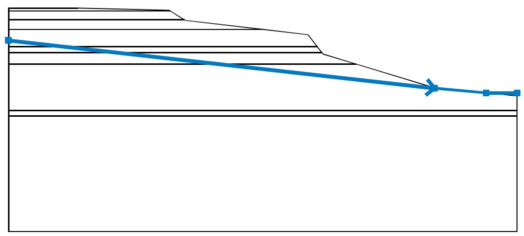
Weathered Bedrock
Unit weight : γ = 140.0 pcf
Angle of internal friction : φ_{ef} = 30.00 °
Cohesion of soil : c_{ef} = 0.0 psf
Saturated unit weight : γ_{sat} = 140.0 pcf

Assigning and surfaces

Number	Surface position	Coordinates of surface points [ft]				Assigned soil
		x	z	x	z	
1		80.00	70.93	80.24	70.93	Silty Sand/Clayey Silt
		79.49	71.41	0.00	73.43	
		-60.00	73.43	-60.00	70.93	

Number	Surface position	Coordinates of surface points [ft]				Assigned soil
		x	z	x	z	
2		90.00	63.43	91.97	63.43	Sandy Clay
		80.24	70.93	80.00	70.93	
		-60.00	70.93	-60.00	63.43	
3		152.00	54.93	160.65	54.93	Sand
		92.92	62.82	91.97	63.43	
		90.00	63.43	-60.00	63.43	
		-60.00	54.93			
4		205.00	39.93	207.29	39.93	Sandy/Clayey Silt
		199.19	50.44	160.65	54.93	
		152.00	54.93	-60.00	54.93	
		-60.00	39.93			
5		210.00	34.93	211.14	34.93	Silty Clay-1
		207.29	39.93	205.00	39.93	
		-60.00	39.93	-60.00	34.93	
6		240.00	24.93	240.95	24.93	Silty Sand
		212.08	33.71	211.14	34.93	
		210.00	34.93	-60.00	34.93	
		-60.00	24.93			
7		380.00	-15.07	380.00	-2.60	Silty Clay-2
		353.35	0.00	308.59	4.36	
		240.95	24.93	240.00	24.93	
		-60.00	24.93	-60.00	-15.07	
8		380.00	-20.07	380.00	-15.07	Clayey Silt
		-60.00	-15.07	-60.00	-20.07	
9		-60.00	-20.07	-60.00	-120.07	Weathered Bedrock
		380.00	-120.07	380.00	-20.07	

Water
Water type : GWT

Number	GWT location	Coordinates of GWT points [ft]					
		x	z	x	z	x	z
1		-60.00	45.43	308.58	4.00	353.15	0.00
		380.00	0.00				

Tensile crack
Depth of tensile crack : 4.00 ft

Earthquake
Earthquake not included.

Analysis settings
Analysis settings : USA
Analysis type : Safety factor
Safety factor : 1.30

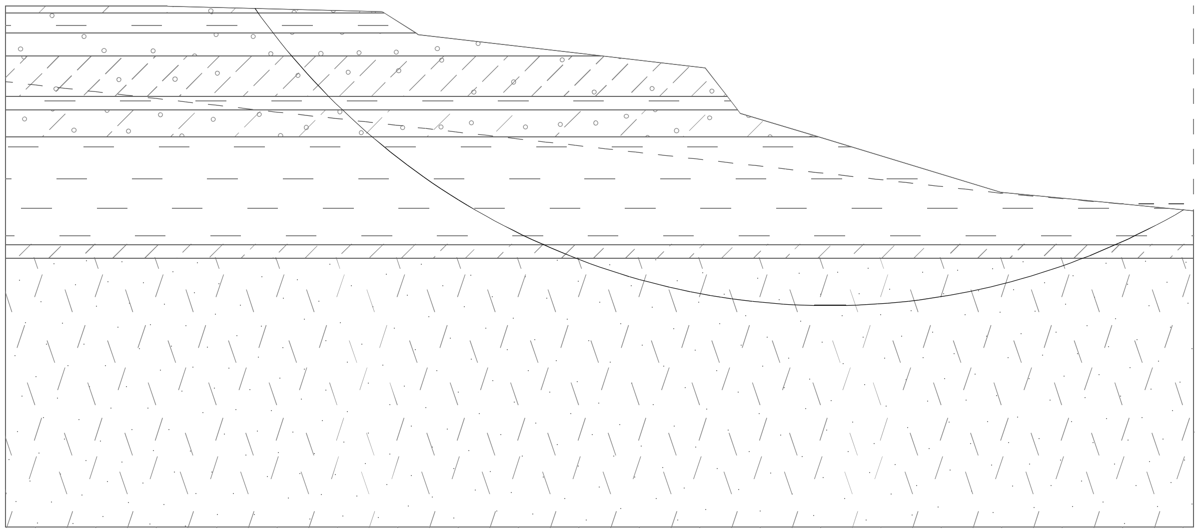
Results (Stage of construction 1)

Analysis 1
Circular slip surface

Slip surface parameters							
Center :	x =	245.15	[ft]	Angles :	α_1 =	-54.85	[°]
	z =	222.36	[ft]		α_2 =	30.29	[°]
Radius :	R =	260.11	[ft]				
The slip surface after optimization.							

Slope stability verification (Bishop)
Sum of active forces : F_a = 452353.1 lbf/ft
Sum of passive forces : F_p = 961081.8 lbf/ft
Sliding moment : M_a = 117739121.5 lbfft/ft
Resisting moment : M_p = 249989842.8 lbfft/ft
Factor of safety = 2.12 > 1.30
Slope stability SATISFACTORY

Name : Analysis	Stage - analysis : 1 - 1



Slope Stability Analysis

Project: Grant Park

Task : Check for Global Stability – Existing Failed Slope
Polygonal Slip Surface

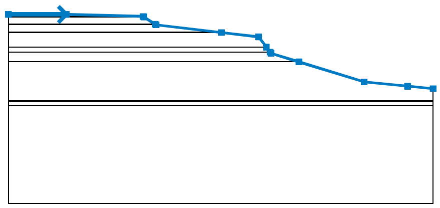
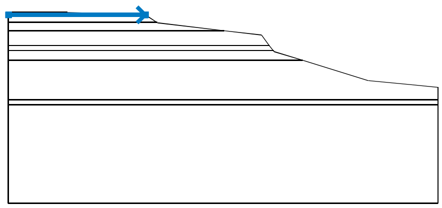
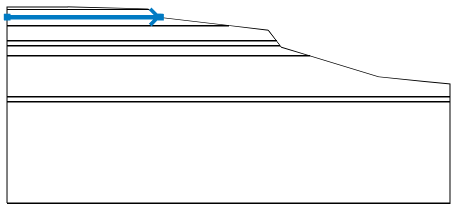
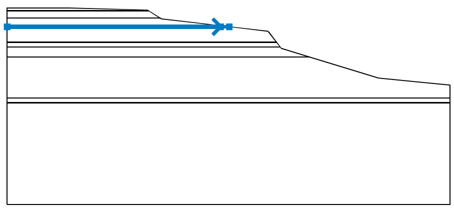
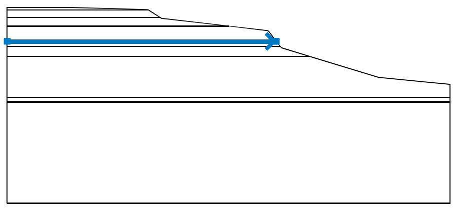
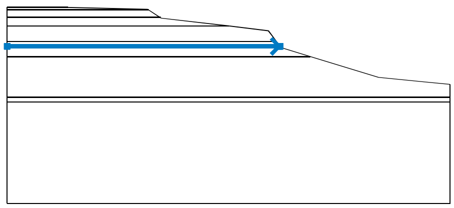
Description : Grant Park Bluff Stabilization, Milwaukee County

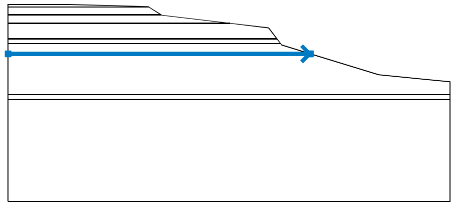
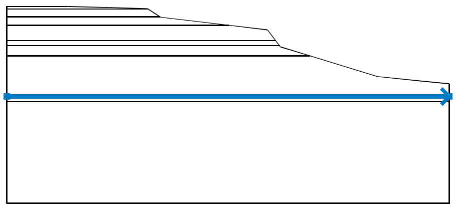
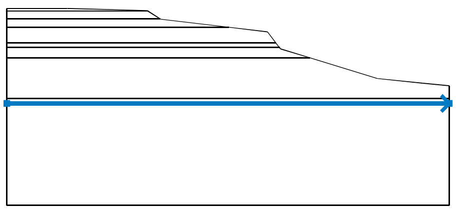
Author : GKA

Date : 11/2/2011

Analysis type : in effective parameters

Interface

Number	Interface location	Coordinates of interface points [ft]					
		x	z	x	z	x	z
1		-60.00	73.43	0.00	73.43	79.49	71.41
		80.24	70.93	91.97	63.43	92.92	62.82
		160.65	54.93	199.19	50.44	207.29	39.93
		211.14	34.93	212.08	33.71	240.95	24.93
		308.59	4.36	353.35	0.00	380.00	-2.60
2		-60.00	70.93	80.00	70.93	80.24	70.93
3		-60.00	63.43	90.00	63.43	91.97	63.43
4		-60.00	54.93	152.00	54.93	160.65	54.93
5		-60.00	39.93	205.00	39.93	207.29	39.93
6		-60.00	34.93	210.00	34.93	211.14	34.93

Number	Interface location	Coordinates of interface points [ft]					
		x	z	x	z	x	z
7		-60.00	24.93	240.00	24.93	240.95	24.93
8		-60.00	-15.07	380.00	-15.07		
9		-60.00	-20.07	380.00	-20.07		

Soil parameters - effective stress state

Number	Name	Pattern	φ_{ef} [°]	c_{ef} [psf]	γ [pcf]
1	Silty Sand/Clayey Silt		27.00	0.0	95.0
2	Sandy Clay		0.00	1300.0	120.0
3	Sand		34.00	0.0	120.0
4	Sandy/Clayey Silt		0.00	1250.0	125.0
5	Silty Clay-1		0.00	2500.0	130.0
6	Silty Sand to Clayey Silt		32.00	0.0	125.0
7	Silty Clay-2		0.00	2750.0	128.0
8	Clayey Silt		0.00	4500.0	132.0

Number	Name	Pattern	φ_{ef} [°]	c_{ef} [psf]	γ [pcf]
9	Weathered Bedrock		30.00	0.0	140.0

Soil parameters - uplift

Number	Name	Pattern	γ_{sat} [pcf]	γ_s [pcf]	n [–]
1	Silty Sand/Clayey Silt		95.0		
2	Sandy Clay		120.0		
3	Sand		120.0		
4	Sandy/Clayey Silt		125.0		
5	Silty Clay-1		130.0		
6	Silty Sand		125.0		
7	Silty Clay-2		128.0		
8	Clayey Silt		132.0		
9	Weathered Bedrock		140.0		

Soil parameters

Silty Sand/Clayey Silt

Unit weight : γ = 95.0 pcf
Angle of internal friction : φ_{ef} = 27.00 °
Cohesion of soil : c_{ef} = 0.0 psf
Saturated unit weight : γ_{sat} = 95.0 pcf

Sandy Clay

Unit weight : γ = 120.0 pcf
Angle of internal friction : φ_{ef} = 0.00 °
Cohesion of soil : c_{ef} = 1300.0 psf
Saturated unit weight : γ_{sat} = 120.0 pcf

Sand

Unit weight :	γ	=	120.0 pcf
Angle of internal friction :	φ_{ef}	=	34.00 °
Cohesion of soil :	c_{ef}	=	0.0 psf
Saturated unit weight :	γ_{sat}	=	120.0 pcf

Sandy/Clayey Silt

Unit weight :	γ	=	125.0 pcf
Angle of internal friction :	φ_{ef}	=	0.00 °
Cohesion of soil :	c_{ef}	=	1250.0 psf
Saturated unit weight :	γ_{sat}	=	125.0 pcf

Silty Clay-1

Unit weight :	γ	=	130.0 pcf
Angle of internal friction :	φ_{ef}	=	0.00 °
Cohesion of soil :	c_{ef}	=	2500.0 psf
Saturated unit weight :	γ_{sat}	=	130.0 pcf

Silty Sand to Clayey Silt

Unit weight :	γ	=	125.0 pcf
Angle of internal friction :	φ_{ef}	=	32.00 °
Cohesion of soil :	c_{ef}	=	0.0 psf
Saturated unit weight :	γ_{sat}	=	125.0 pcf

Silty Clay-2

Unit weight :	γ	=	128.0 pcf
Angle of internal friction :	φ_{ef}	=	0.00 °
Cohesion of soil :	c_{ef}	=	2750.0 psf
Saturated unit weight :	γ_{sat}	=	128.0 pcf

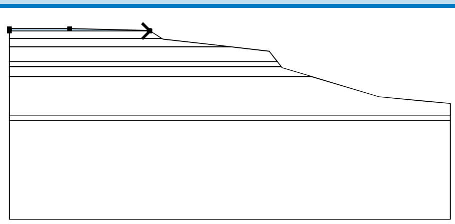
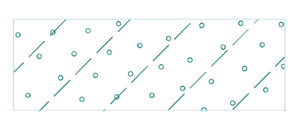
Clayey Silt

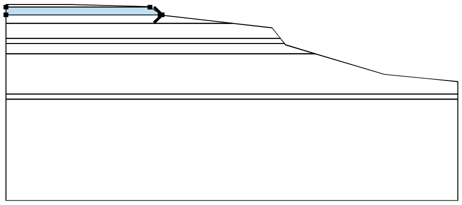
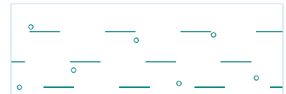
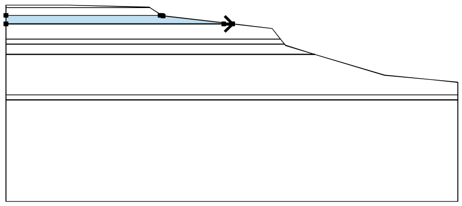
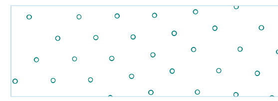
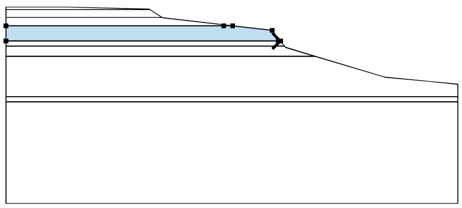
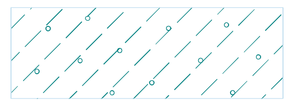
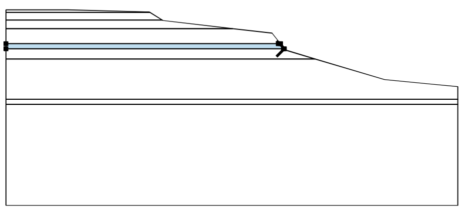
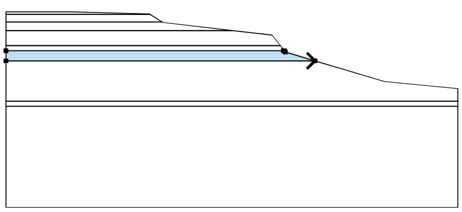
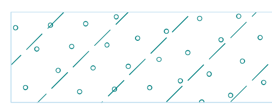
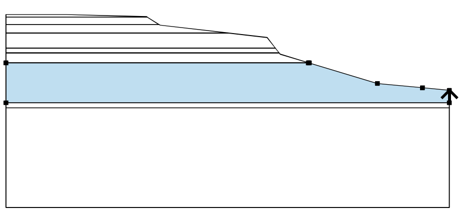
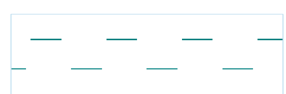
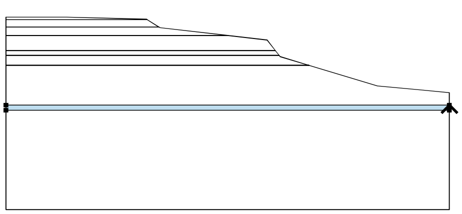
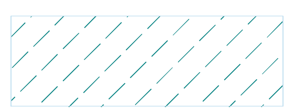
Unit weight :	γ	=	132.0 pcf
Angle of internal friction :	φ_{ef}	=	0.00 °
Cohesion of soil :	c_{ef}	=	4500.0 psf
Saturated unit weight :	γ_{sat}	=	132.0 pcf

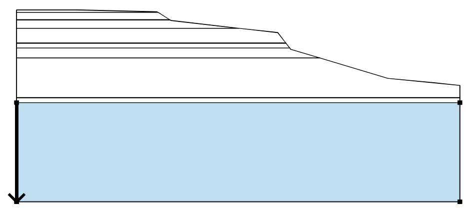
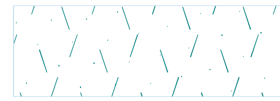
Weathered Bedrock

Unit weight :	γ	=	140.0 pcf
Angle of internal friction :	φ_{ef}	=	30.00 °
Cohesion of soil :	c_{ef}	=	0.0 psf
Saturated unit weight :	γ_{sat}	=	140.0 pcf

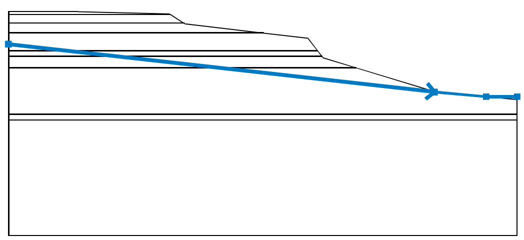
Assigning and surfaces

Number	Surface position	Coordinates of surface points [ft]				Assigned soil
		x	z	x	z	
1		80.00	70.93	80.24	70.93	Silty Sand/Clayey Silt
		79.49	71.41	0.00	73.43	
		-60.00	73.43	-60.00	70.93	

Number	Surface position	Coordinates of surface points [ft] x	z	x	z	Assigned soil
2		90.00	63.43	91.97	63.43	Sandy Clay 
		80.24	70.93	80.00	70.93	
		-60.00	70.93	-60.00	63.43	
3		152.00	54.93	160.65	54.93	Sand 
		92.92	62.82	91.97	63.43	
		90.00	63.43	-60.00	63.43	
		-60.00	54.93			
4		205.00	39.93	207.29	39.93	Sandy/Clayey Silt 
		199.19	50.44	160.65	54.93	
		152.00	54.93	-60.00	54.93	
		-60.00	39.93			
5		210.00	34.93	211.14	34.93	Silty Clay-1 
		207.29	39.93	205.00	39.93	
		-60.00	39.93	-60.00	34.93	
6		240.00	24.93	240.95	24.93	Silty Sand 
		212.08	33.71	211.14	34.93	
		210.00	34.93	-60.00	34.93	
		-60.00	24.93			
7		380.00	-15.07	380.00	-2.60	Silty Clay-2 
		353.35	0.00	308.59	4.36	
		240.95	24.93	240.00	24.93	
		-60.00	24.93	-60.00	-15.07	
8		380.00	-20.07	380.00	-15.07	Clayey Silt 
		-60.00	-15.07	-60.00	-20.07	

Number	Surface position	Coordinates of surface points [ft]				Assigned soil
		x	z	x	z	
9		-60.00	-20.07	-60.00	-120.07	Weathered Bedrock 
		380.00	-120.07	380.00	-20.07	

Water
Water type : GWT

Number	GWT location	Coordinates of GWT points [ft]					
		x	z	x	z	x	z
1		-60.00	45.43	308.58	4.00	353.15	0.00
		380.00	0.00				

Tensile crack
Depth of tensile crack : 4.00 ft

Earthquake
Earthquake not included.

Analysis settings
Analysis settings : USA
Analysis type : Safety factor
Safety factor : 1.30

Results (Stage of construction 1)

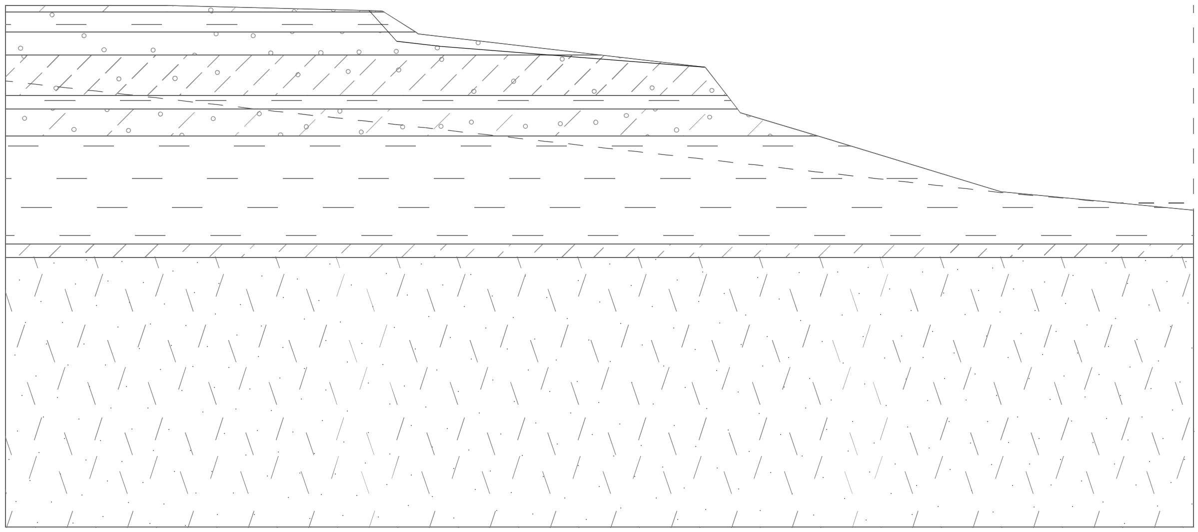
Analysis 1
Polygonal slip surface

Coordinates of slip surface points [ft]									
x	z	x	z	x	z	x	z	x	z
74.64	71.53	84.92	60.08	101.38	58.13	198.95	50.47		
The slip surface after optimization.									

Slope stability verification (Sarma)
Factor of safety = 1.09 < 1.30
Slope stability NOT SATISF.

Name : Analysis	Stage - analysis : 1 - 1

Name : Analysis	Stage - analysis : 1 - 1



ADJACENT UNFAILED SLOPE

(Section B-B)

Profile View of Section B–B : Adjacent Unfailed Slope

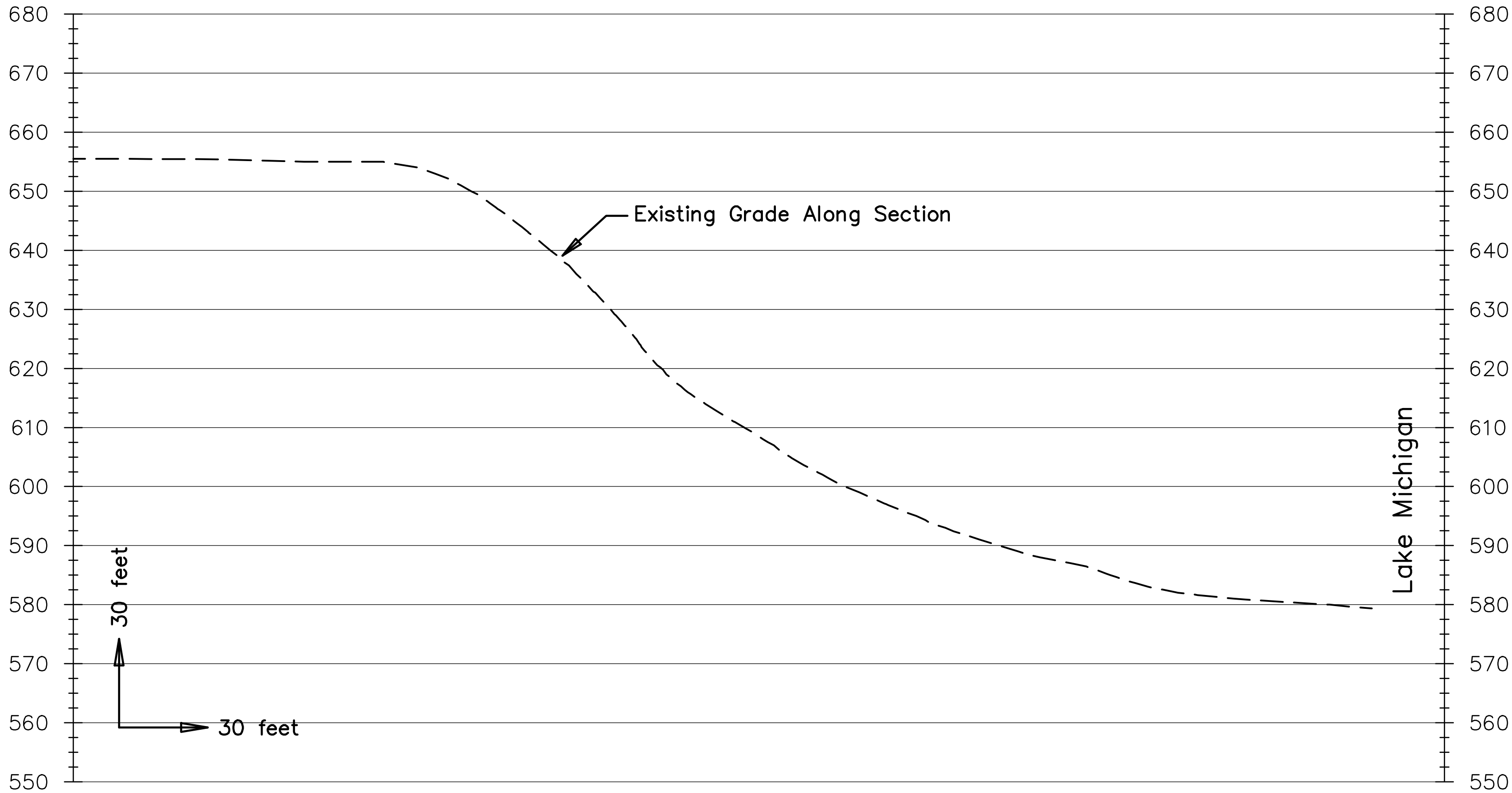


Figure **D-3**

Global Stability Analysis
Grant Park FEMA Restoration
Base Map Provided By Collins Engineering

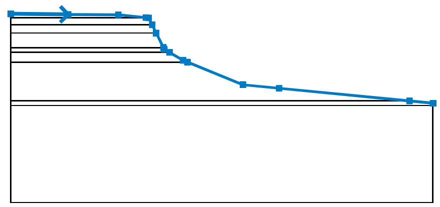
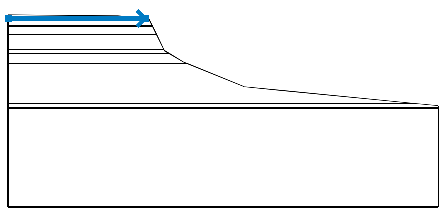
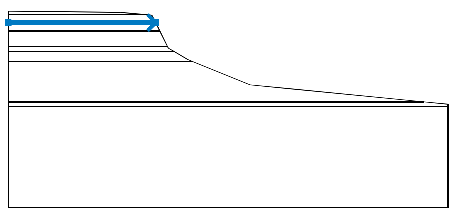
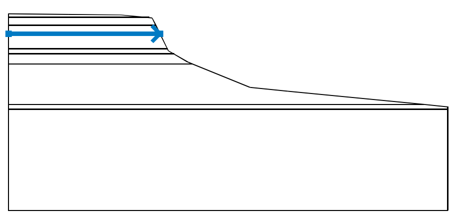
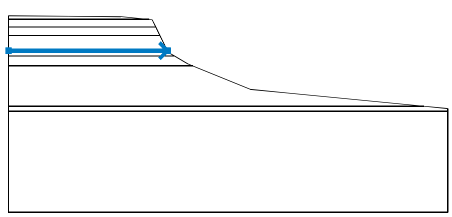
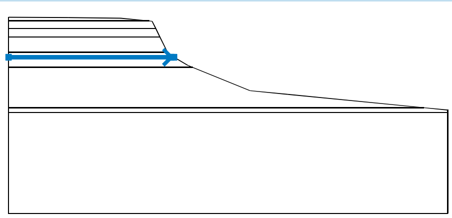
Himalayan Consultants, LLC
Engineers and Hydrogeologists
W156 N11357 Pilgrim Road
Germantown, Wisconsin 53022
Phone: (262) 502-0066
Fax: (262) 502-0066

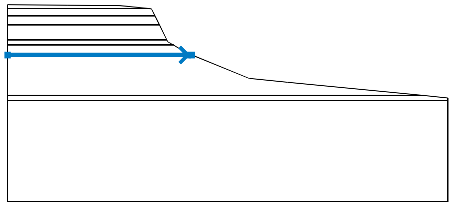
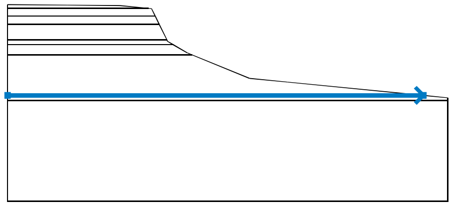
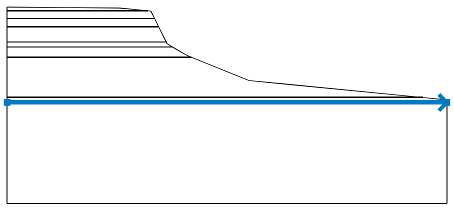
Slope Stability Analysis

Project: Grant Park

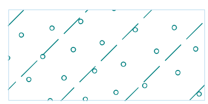
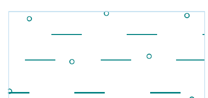
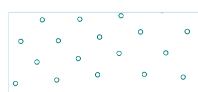
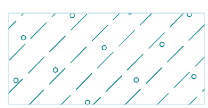
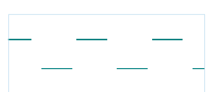
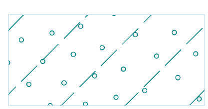
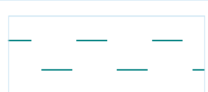
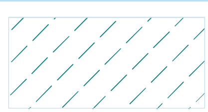
Task : Check for Global Stability-Existing Unfailed Slope
Circular Slip Surface
Description : Grant Park Slope Stabilization
Author : GKA
Date : 11/3/2011
Analysis type : in effective parameters

Interface

Number	Interface location	Coordinates of interface points [ft]					
		x	z	x	z	x	z
1		-60.00	76.67	0.00	76.12	52.31	75.64
		80.74	72.93	83.78	72.64	87.38	65.43
		91.62	56.93	99.11	41.93	100.00	40.15
		105.53	36.93	119.58	28.75	124.10	26.93
		181.95	3.64	219.77	0.00	355.58	-13.07
		380.00	-15.42				
2		-60.00	72.93	80.00	72.93	80.74	72.93
3		-60.00	65.43	87.38	65.43		
4		-60.00	56.93	91.62	56.93		
5		-60.00	41.93	99.11	41.93		
6		-60.00	36.93	103.00	36.93	105.53	36.93

Number	Interface location	Coordinates of interface points [ft]					
		x	z	x	z	x	z
7		-60.00	26.93	120.00	26.93	124.10	26.93
8		-60.00	-13.07	355.58	-13.07		
9		-60.00	-18.07	380.00	-18.07		

Soil parameters - effective stress state

Number	Name	Pattern	φ_{ef} [°]	c_{ef} [psf]	γ [pcf]
1	Silty Sand/Clayey Silt		27.00	0.0	95.0
2	Sandy Clay		0.00	1300.0	120.0
3	Sand		34.00	0.0	120.0
4	Sandy/Clayey Silt		0.00	1250.0	125.0
5	Silty Clay-1		0.00	2500.0	130.0
6	Silty Sand to Clayey Silt		32.00	0.0	125.0
7	Silty Clay-2		0.00	2750.0	128.0
8	Clayey Silt		0.00	4500.0	132.0

Number	Name	Pattern	φ_{ef} [°]	c_{ef} [psf]	γ [pcf]
9	Waethered Bedrock		30.00	0.0	140.0

Soil parameters - uplift

Number	Name	Pattern	γ_{sat} [pcf]	γ_s [pcf]	n [–]
1	Silty Sand/Clayey Silt		95.0		
2	Sandy Clay		120.0		
3	Sand		120.0		
4	Sandy/Clayey Silt		125.0		
5	Silty Clay-1		130.0		
6	Silty Sand		125.0		
7	Silty Clay-2		128.0		
8	Clayey Silt		132.0		
9	Waethered Bedrock		140.0		

Soil parameters

Silty Sand/Clayey Silt

Unit weight : γ = 95.0 pcf
Angle of internal friction : φ_{ef} = 27.00 °
Cohesion of soil : c_{ef} = 0.0 psf
Saturated unit weight : γ_{sat} = 95.0 pcf

Sandy Clay

Unit weight : γ = 120.0 pcf
Angle of internal friction : φ_{ef} = 0.00 °
Cohesion of soil : c_{ef} = 1300.0 psf
Saturated unit weight : γ_{sat} = 120.0 pcf

Sand

Unit weight :	γ	=	120.0 pcf
Angle of internal friction :	φ_{ef}	=	34.00 °
Cohesion of soil :	c_{ef}	=	0.0 psf
Saturated unit weight :	γ_{sat}	=	120.0 pcf

Sandy/Clayey Silt

Unit weight :	γ	=	125.0 pcf
Angle of internal friction :	φ_{ef}	=	0.00 °
Cohesion of soil :	c_{ef}	=	1250.0 psf
Saturated unit weight :	γ_{sat}	=	125.0 pcf

Silty Clay-1

Unit weight :	γ	=	130.0 pcf
Angle of internal friction :	φ_{ef}	=	0.00 °
Cohesion of soil :	c_{ef}	=	2500.0 psf
Saturated unit weight :	γ_{sat}	=	130.0 pcf

Silty Sand to Clayey Silt

Unit weight :	γ	=	125.0 pcf
Angle of internal friction :	φ_{ef}	=	32.00 °
Cohesion of soil :	c_{ef}	=	0.0 psf
Saturated unit weight :	γ_{sat}	=	125.0 pcf

Silty Clay-2

Unit weight :	γ	=	128.0 pcf
Angle of internal friction :	φ_{ef}	=	0.00 °
Cohesion of soil :	c_{ef}	=	2750.0 psf
Saturated unit weight :	γ_{sat}	=	128.0 pcf

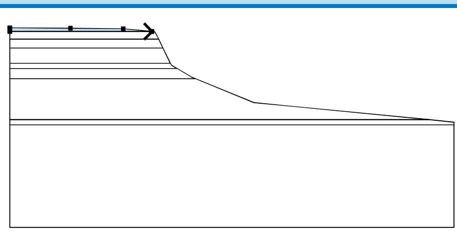
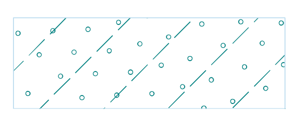
Clayey Silt

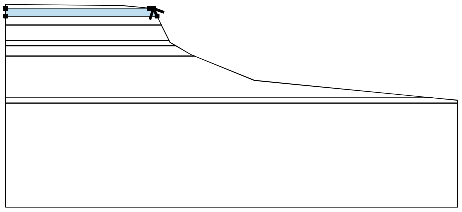
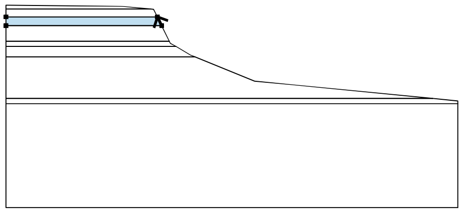
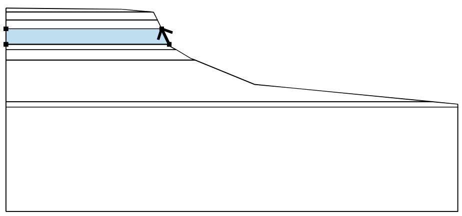
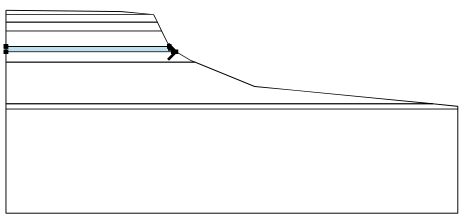
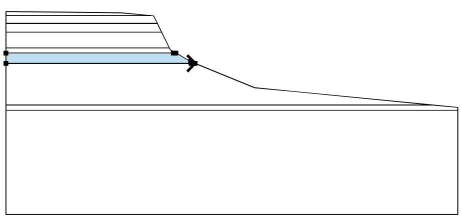
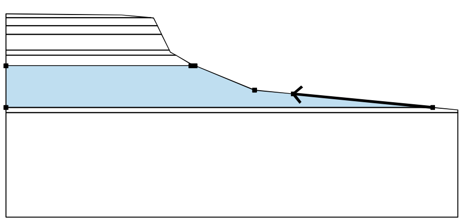
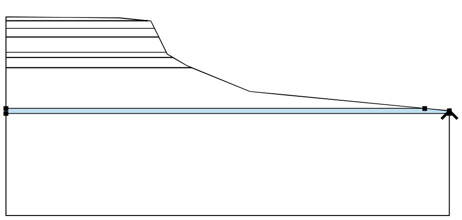
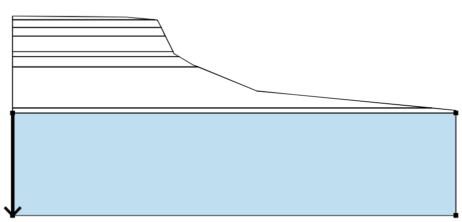
Unit weight :	γ	=	132.0 pcf
Angle of internal friction :	φ_{ef}	=	0.00 °
Cohesion of soil :	c_{ef}	=	4500.0 psf
Saturated unit weight :	γ_{sat}	=	132.0 pcf

Weathered Bedrock

Unit weight :	γ	=	140.0 pcf
Angle of internal friction :	φ_{ef}	=	30.00 °
Cohesion of soil :	c_{ef}	=	0.0 psf
Saturated unit weight :	γ_{sat}	=	140.0 pcf

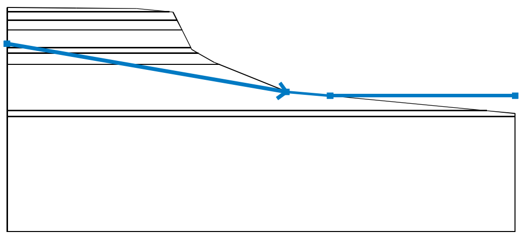
Assigning and surfaces

Number	Surface position	Coordinates of surface points [ft]				Assigned soil
		x	z	x	z	
1		80.00	72.93	80.74	72.93	Silty Sand/Clayey Silt
		52.31	75.64	0.00	76.12	
		-60.00	76.67	-60.00	72.93	

Number	Surface position	Coordinates of surface points [ft] x	z	x	z	Assigned soil
2		87.38	65.43	83.78	72.64	Sandy Clay
		80.74	72.93	80.00	72.93	
		-60.00	72.93	-60.00	65.43	
3		91.62	56.93	87.38	65.43	Sand
		-60.00	65.43	-60.00	56.93	
4		99.11	41.93	91.62	56.93	Sandy/Clayey Silt
		-60.00	56.93	-60.00	41.93	
5		103.00	36.93	105.53	36.93	Silty Clay-1
		100.00	40.15	99.11	41.93	
		-60.00	41.93	-60.00	36.93	
6		120.00	26.93	124.10	26.93	Silty Sand
		119.58	28.75	105.53	36.93	
		103.00	36.93	-60.00	36.93	
		-60.00	26.93			
7		355.58	-13.07	219.77	0.00	Silty Clay-2
		181.95	3.64	124.10	26.93	
		120.00	26.93	-60.00	26.93	
		-60.00	-13.07			
8		380.00	-18.07	380.00	-15.42	Clayey Silt
		355.58	-13.07	-60.00	-13.07	
		-60.00	-18.07			
9		-60.00	-18.07	-60.00	-118.07	Waethered Bedrock
		380.00	-118.07	380.00	-18.07	

Water

Water type : GWT

Number	GWT location	Coordinates of GWT points [ft]					
		x	z	x	z	x	z
1		-60.00	45.12	181.95	3.30	219.77	0.00
		380.00	0.00				

Tensile crack

Depth of tensile crack : 4.00 ft

Earthquake

Earthquake not included.

Analysis settings

Analysis settings : USA
Analysis type : Safety factor
Safety factor : 1.30

Results (Stage of construction 1)

Analysis 1

Circular slip surface

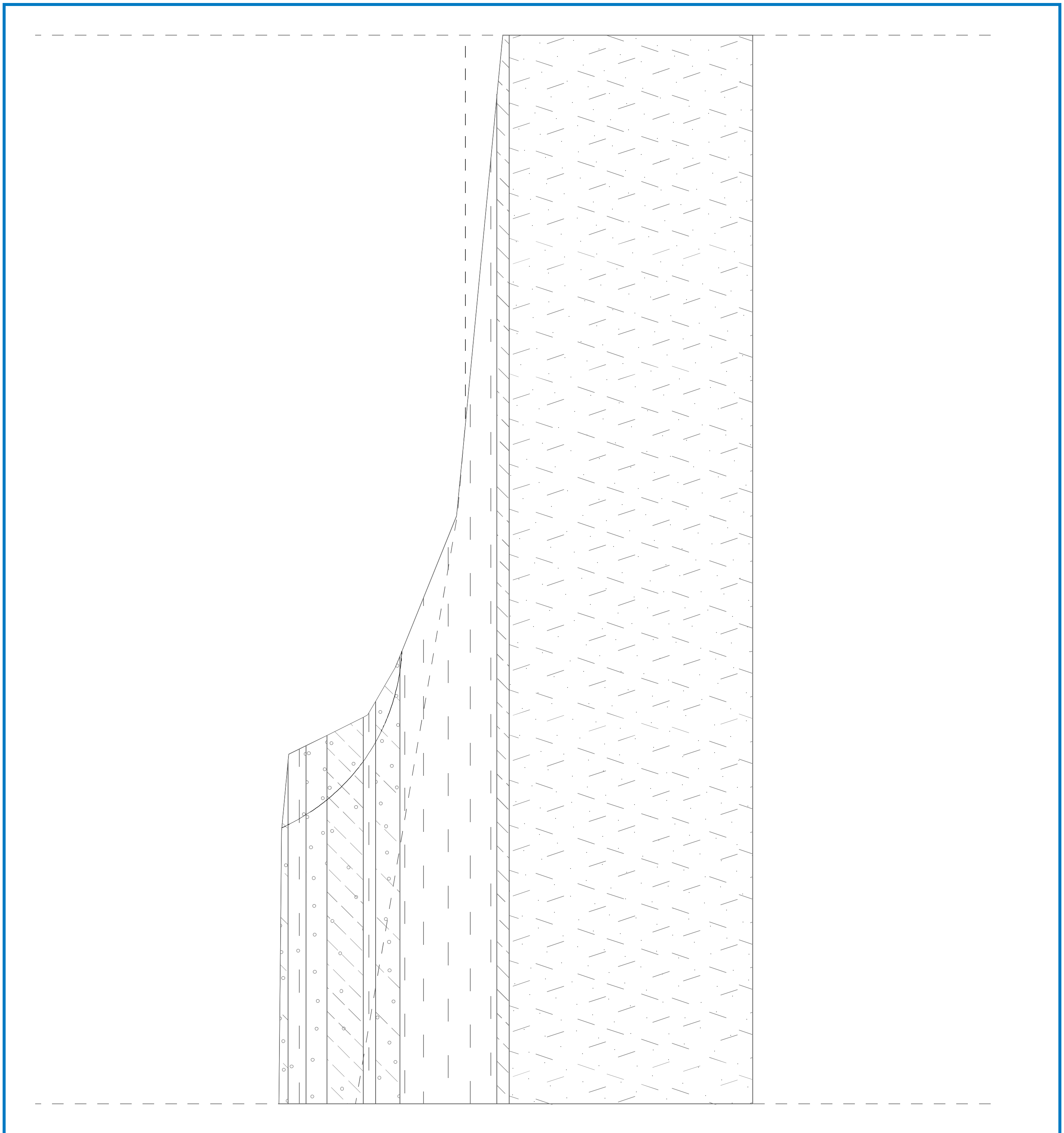
Slip surface parameters							
Center :	x =	130.31	[ft]	Angles :	α_1 =	-65.67	[°]
	z =	110.21	[ft]		α_2 =	-2.82	[°]
Radius :	R =	84.21	[ft]				
The slip surface after optimization.							

Slope stability verification (Bishop)

Sum of active forces : F_a = 72729.1 lbf/ft
Sum of passive forces : F_p = 83628.8 lbf/ft

Sliding moment : M_a = 6143408.4 lbfft/ft
Resisting moment : M_p = 7042621.9 lbfft/ft
Factor of safety = 1.15 < 1.30

Slope stability NOT SATISF.



The slip surface after optimization.

Slope stability verification (Bishop)

Sum of active forces :	F_a =	72714.6	lbf/ft
Sum of passive forces :	F_p =	83616.6	lbf/ft
Sliding moment :	M_a =	6143257.6	lbfft/ft
Resisting moment :	M_p =	7042820.7	lbfft/ft

Factor of safety = 1.15 < 1.30

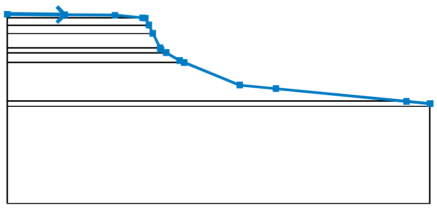
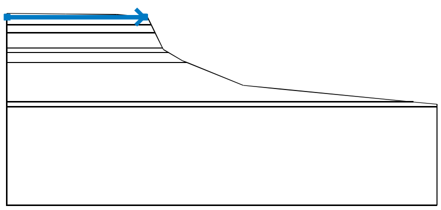
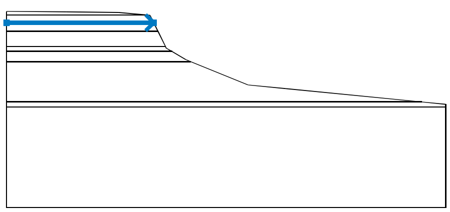
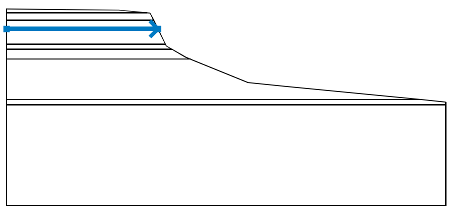
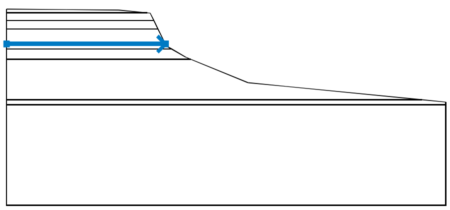
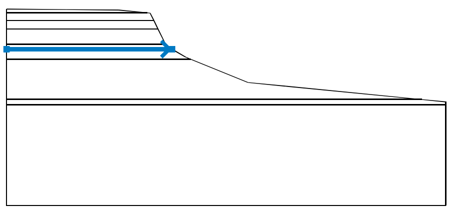
Slope stability NOT SATISF.

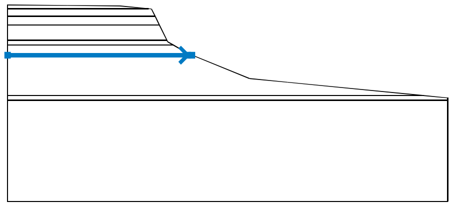
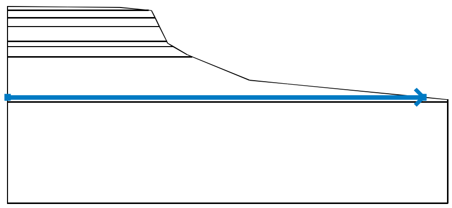
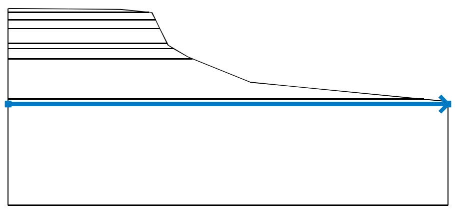
Slope Stability Analysis

Project: Grant Park

Task : Global Stability Analysis - Existing Unfailed Slope
Polygonal Slip Surface
Description : Grant Park Slope Stabilization
Author : GKA
Date : 11/3/2011
Analysis type : in effective parameters

Interface

Number	Interface location	Coordinates of interface points [ft]					
		x	z	x	z	x	z
1		-60.00	76.67	0.00	76.12	52.31	75.64
		80.74	72.93	83.78	72.64	87.38	65.43
		91.62	56.93	99.11	41.93	100.00	40.15
		105.53	36.93	119.58	28.75	124.10	26.93
		181.95	3.64	219.77	0.00	355.58	-13.07
		380.00	-15.42				
2		-60.00	72.93	80.00	72.93	80.74	72.93
3		-60.00	65.43	87.38	65.43		
4		-60.00	56.93	91.62	56.93		
5		-60.00	41.93	99.11	41.93		
6		-60.00	36.93	103.00	36.93	105.53	36.93

Number	Interface location	Coordinates of interface points [ft]					
		x	z	x	z	x	z
7		-60.00	26.93	120.00	26.93	124.10	26.93
8		-60.00	-13.07	355.58	-13.07		
9		-60.00	-18.07	380.00	-18.07		

Soil parameters - effective stress state

Number	Name	Pattern	φ_{ef} [°]	c_{ef} [psf]	γ [pcf]
1	Silty Sand/Clayey Silt		27.00	0.0	95.0
2	Sandy Clay		0.00	1300.0	120.0
3	Sand		34.00	0.0	120.0
4	Sandy/Clayey Silt		0.00	1250.0	125.0
5	Silty Clay-1		0.00	2500.0	130.0
6	Silty Sand to Clayey Silt		32.00	0.0	125.0
7	Silty Clay-2		0.00	2750.0	128.0
8	Clayey Silt		0.00	4500.0	132.0

Number	Name	Pattern	φ_{ef} [°]	c_{ef} [psf]	γ [pcf]
9	Weathered Bedrock		30.00	0.0	140.0

Soil parameters - uplift

Number	Name	Pattern	γ_{sat} [pcf]	γ_s [pcf]	n [–]
1	Silty Sand/Clayey Silt		95.0		
2	Sandy Clay		120.0		
3	Sand		120.0		
4	Sandy/Clayey Silt		125.0		
5	Silty Clay-1		130.0		
6	Silty Sand		125.0		
7	Silty Clay-2		128.0		
8	Clayey Silt		132.0		
9	Waethered Bedrock		140.0		

Soil parameters

Silty Sand/Clayey Silt

Unit weight : γ = 95.0 pcf
Angle of internal friction : φ_{ef} = 27.00 °
Cohesion of soil : c_{ef} = 0.0 psf
Saturated unit weight : γ_{sat} = 95.0 pcf

Sandy Clay

Unit weight : γ = 120.0 pcf
Angle of internal friction : φ_{ef} = 0.00 °
Cohesion of soil : c_{ef} = 1300.0 psf
Saturated unit weight : γ_{sat} = 120.0 pcf

Sand

Unit weight :	γ	=	120.0 pcf
Angle of internal friction :	φ_{ef}	=	34.00 °
Cohesion of soil :	c_{ef}	=	0.0 psf
Saturated unit weight :	γ_{sat}	=	120.0 pcf

Sandy/Clayey Silt

Unit weight :	γ	=	125.0 pcf
Angle of internal friction :	φ_{ef}	=	0.00 °
Cohesion of soil :	c_{ef}	=	1250.0 psf
Saturated unit weight :	γ_{sat}	=	125.0 pcf

Silty Clay-1

Unit weight :	γ	=	130.0 pcf
Angle of internal friction :	φ_{ef}	=	0.00 °
Cohesion of soil :	c_{ef}	=	2500.0 psf
Saturated unit weight :	γ_{sat}	=	130.0 pcf

Silty Sand to Clayey Silt

Unit weight :	γ	=	125.0 pcf
Angle of internal friction :	φ_{ef}	=	32.00 °
Cohesion of soil :	c_{ef}	=	0.0 psf
Saturated unit weight :	γ_{sat}	=	125.0 pcf

Silty Clay-2

Unit weight :	γ	=	128.0 pcf
Angle of internal friction :	φ_{ef}	=	0.00 °
Cohesion of soil :	c_{ef}	=	2750.0 psf
Saturated unit weight :	γ_{sat}	=	128.0 pcf

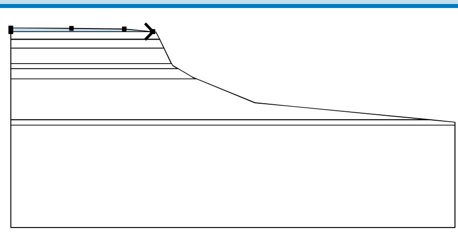
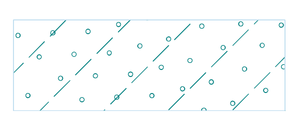
Clayey Silt

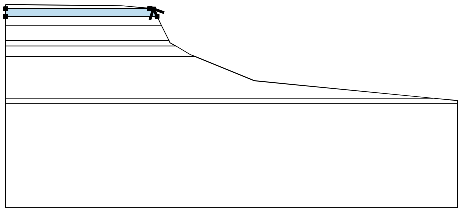
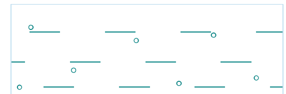
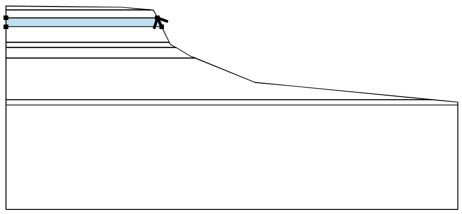
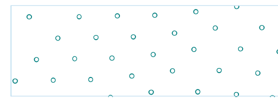
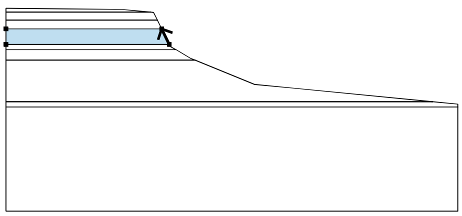
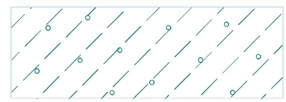
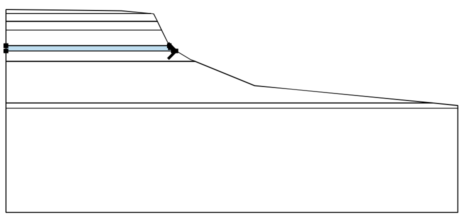
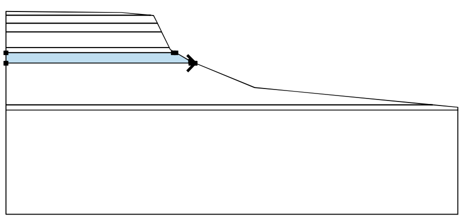
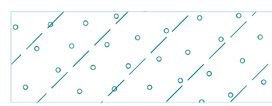
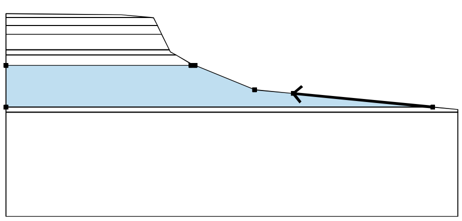
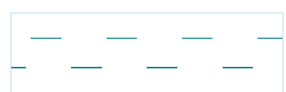
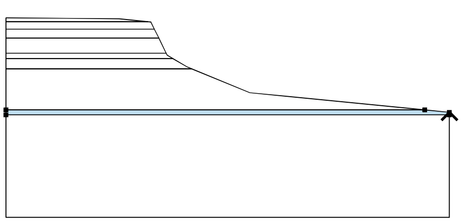
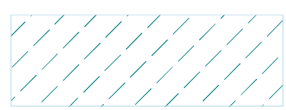
Unit weight :	γ	=	132.0 pcf
Angle of internal friction :	φ_{ef}	=	0.00 °
Cohesion of soil :	c_{ef}	=	4500.0 psf
Saturated unit weight :	γ_{sat}	=	132.0 pcf

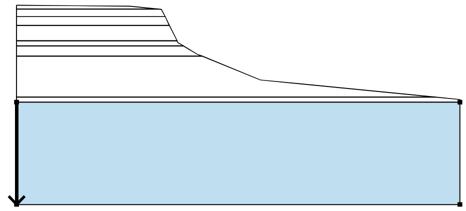
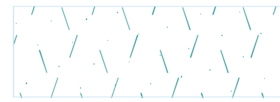
Weathered Bedrock

Unit weight :	γ	=	140.0 pcf
Angle of internal friction :	φ_{ef}	=	30.00 °
Cohesion of soil :	c_{ef}	=	0.0 psf
Saturated unit weight :	γ_{sat}	=	140.0 pcf

Assigning and surfaces

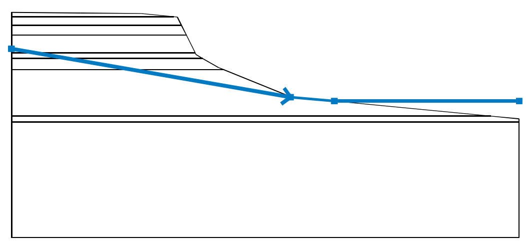
Number	Surface position	Coordinates of surface points [ft]				Assigned soil
		x	z	x	z	
1		80.00	72.93	80.74	72.93	Silty Sand/Clayey Silt
		52.31	75.64	0.00	76.12	
		-60.00	76.67	-60.00	72.93	

Number	Surface position	Coordinates of surface points [ft]				Assigned soil
		x	z	x	z	
2		87.38	65.43	83.78	72.64	Sandy Clay
		80.74	72.93	80.00	72.93	
		-60.00	72.93	-60.00	65.43	
3		91.62	56.93	87.38	65.43	Sand
		-60.00	65.43	-60.00	56.93	
4		99.11	41.93	91.62	56.93	Sandy/Clayey Silt
		-60.00	56.93	-60.00	41.93	
5		103.00	36.93	105.53	36.93	Silty Clay-1
		100.00	40.15	99.11	41.93	
		-60.00	41.93	-60.00	36.93	
6		120.00	26.93	124.10	26.93	Silty Sand
		119.58	28.75	105.53	36.93	
		103.00	36.93	-60.00	36.93	
		-60.00	26.93			
7		355.58	-13.07	219.77	0.00	Silty Clay-2
		181.95	3.64	124.10	26.93	
		120.00	26.93	-60.00	26.93	
		-60.00	-13.07			
8		380.00	-18.07	380.00	-15.42	Clayey Silt
		355.58	-13.07	-60.00	-13.07	
		-60.00	-18.07			

Number	Surface position	Coordinates of surface points [ft]				Assigned soil
		x	z	x	z	
9		-60.00	-18.07	-60.00	-118.07	Waethered Bedrock
		380.00	-118.07	380.00	-18.07	

Water

Water type : GWT

Number	GWT location	Coordinates of GWT points [ft]					
		x	z	x	z	x	z
1		-60.00	45.12	181.95	3.30	219.77	0.00
		380.00	0.00				

Tensile crack

Depth of tensile crack : 4.00 ft

Earthquake

Earthquake not included.

Analysis settings

Analysis settings : USA
Analysis type : Safety factor
Safety factor : 1.30

Results (Stage of construction 1)

Analysis 1

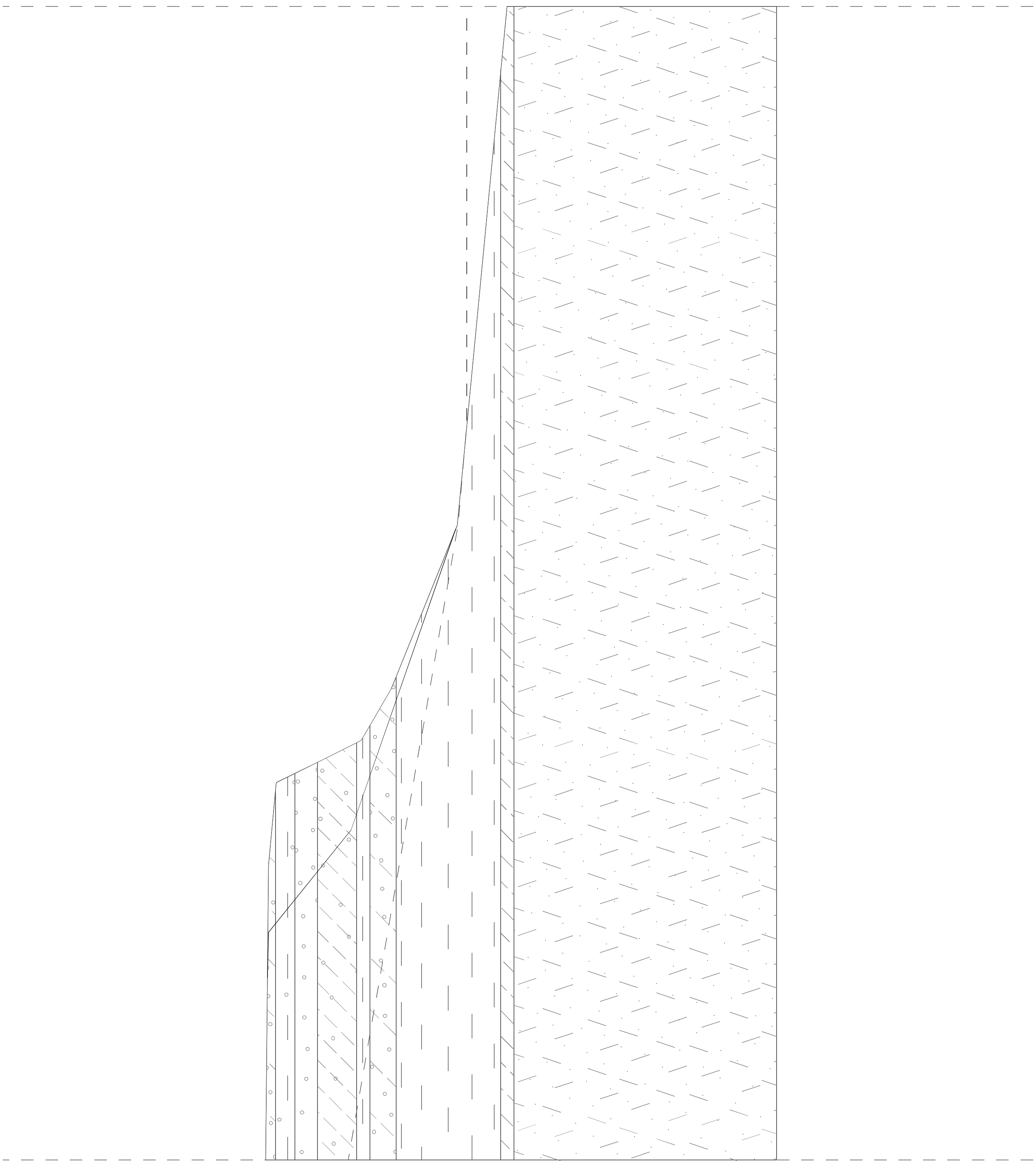
Polygonal slip surface

Coordinates of slip surface points [ft]									
x	z	x	z	x	z	x	z	x	z
9.45	76.03	26.62	75.58	65.73	44.12	180.64	4.17		
The slip surface after optimization.									

Slope stability verification (Sarma)

Factor of safety = 1.29 < 1.30

Slope stability NOT SATISF.



The slip surface after optimization.

Slope stability verification (Sarma)

Factor of safety = 1.29 < 1.30

Slope stability NOT SATISF.

APPENDIX E

SITE PHOTOGRAPHS

Photograph #1: View of Horizontal Limit of Slope Failure Area (East View)

Photograph #2: View of Vertical Limit of Slope Failure (West View)